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# QUIET CLEAN SHORT-HAUL EXPERIMENTAL ENGINE (QCSEE)

## OVER-THE-WING (OTW) BOILERPLATE NACELLE DESIGN REPORT

(NASA-CR-135168) QUIET CLEAN SHORT-HAUL  
EXPERIMENTAL ENGINE (QCSEE) OVER-THE-WING  
(OTW) BOILERPLATE NACELLE DESIGN REPORT  
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16. Abstract  This report is a summary of the mechanical design of the boilerplate nacelle for the QCSEE Over-the-Wing (OTW) engine. The nacelle, which features a "D"-shaped nozzle/thrust reverser and interchangeable hard wall and acoustic panels, is to be utilized in the engine testing to establish the aerodynamic and acoustic requirements for nozzles and reversers of this type.			
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## FOREWORD

The major objective of the QCSEE Program is to develop and demonstrate the technology required for propulsion systems for quiet, clean, and economically viable commercial short-haul aircraft. The program includes design, fabrication, and testing of a gear-driven variable pitch turbofan engine for under-the-wing (UTW) installation and a gear-driven fixed-pitch turbofan engine for over-the-wing (OTW) installation. Both experimental engines will utilize the F101 core and LP turbine.

The material presented within this document consists of the design of the boilerplate nacelle to be used in the aeromechanical and acoustical evaluation of the QCSEE OTW engine. Also presented are the analytical techniques and the engineering evaluation used to arrive at the final mechanical design.

This report documents the design of the boilerplate nacelle emphasizing the D-shaped nozzle and thrust reverser system. Every major component of the UTW nacelle except the pylon closeout (boattail) will be utilized for the OTW engine testing.

## SECTION I

### INTRODUCTION

The detail mechanical design of the over-the-wing (OTW) boilerplate nacelle to be used in the aeromechanical and acoustical evaluation of the OTW engine in the NASA QCSEE program is presented in this report. The structural, mechanical, and material characteristics of the QCSEE boilerplate components are similar to those of recently developed test nacelles for the Quiet Engine program and CFM56 series engines. The design intent is to fabricate durable and fatigue-resistant nacelle components. This is accomplished through the use of heavy-gage metals in sheet extrusion and bar form, which has proved to be a consistent and economical method of making nacelle components for testing engines of this type.

Economies in the QCSEE program were accomplished by designing major nacelle components that were interchangeable between the various propulsion system configurations. All of the under-the-wing (UTW) boilerplate nacelle hardware will be used, and it will make up a significant proportion of the OTW propulsion system. The design and operation of those UTW nacelle components are described in the Under-The-Wing Boilerplate Nacelle and Core Exhaust Nozzle Design Report, CR 135008. Additional hardware is required to satisfy the OTW propulsion system. The major item for this system is the D-shaped nozzle/thrust reverser. It is the intent of this document to present a complete description of the mechanical design and analysis of those new hardware components.

Another economy measure employed in this effort is to utilize all of the acoustic treatment and hard wall panels from the UTW propulsion system. Acoustically this includes one complete set of single-degree-of-freedom (SDOF) panels plus an additional set of Kevlar panels (bulk absorber) for the hybrid inlet. The material required for additional panels is available to reduce turnaround time, if the acoustic test results do not meet QCSEE noise reduction goals.

## SECTION II

### NACELLE DESCRIPTION - UTW HARDWARE

Presented in this section is a description of the UTW boilerplate nacelle hardware. The nacelle was fabricated by GE-Mojave under a detail design and build contract.

It is not the intent of this report to reproduce the nacelle description in detail for the following UTW boilerplate nacelle components that will be utilized on the OTW engine:

1. Acoustic treatment design including single-degree-of-freedom and bulk absorber configurations.
2. Hybrid inlet, bellmouth inlet, and massive acoustic-suppressor inlet requirements.
3. Fan doors, core doors, acoustic splitter, and forward pylon and pylon support assembly.

These components are described in detail in the Under-The-Wing Boilerplate Nacelle and Core Exhaust Nozzle Design Report, CR 135008.

#### A. INLET

Testing of the OTW engine will require three boilerplate inlet configurations. The NASA Quiet Engine "C" bellmouth inlet assembly (Figure 1) will be utilized for aerodynamic engine mapping and baseline acoustic evaluation. A four-ring splitter massive inlet suppressor (Figure 2), also borrowed from the Quiet Engine "C" program, will be utilized to isolate aft-end noise and provide additional information for acoustic evaluation. A hybrid inlet (Figure 3), featuring elevated throat Mach numbers and two acoustic suppression designs [SDOF (Figure 4) and bulk absorber (Figure 5)], will be employed from the QCSEE UTW program for the aerodynamic and acoustic evaluations. As a result of their non-flight weight construction, all inlets will be mechanically decoupled from the engine (Figure 6) to prevent overload of the composite fan frame due to excessive engine motion/vibration. The air seal is provided by an open-cell foam, Scottfelt, bonded to one-half of the flange and pressed to the other. A lead foil in the form of a vinyl cover provides the aero/acoustic seal. This seal configuration aerodynamically and acoustically simulates a hard-joint condition that typifies a flight weight propulsion system assembly.

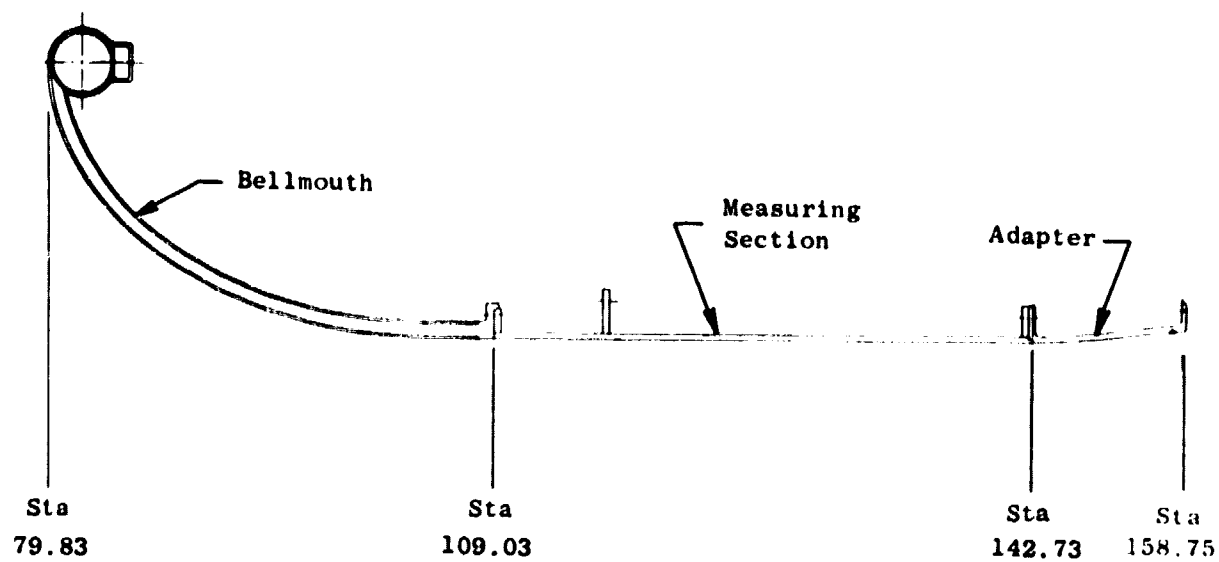


Figure 1. Boilerplate Inlet, Bellmouth.

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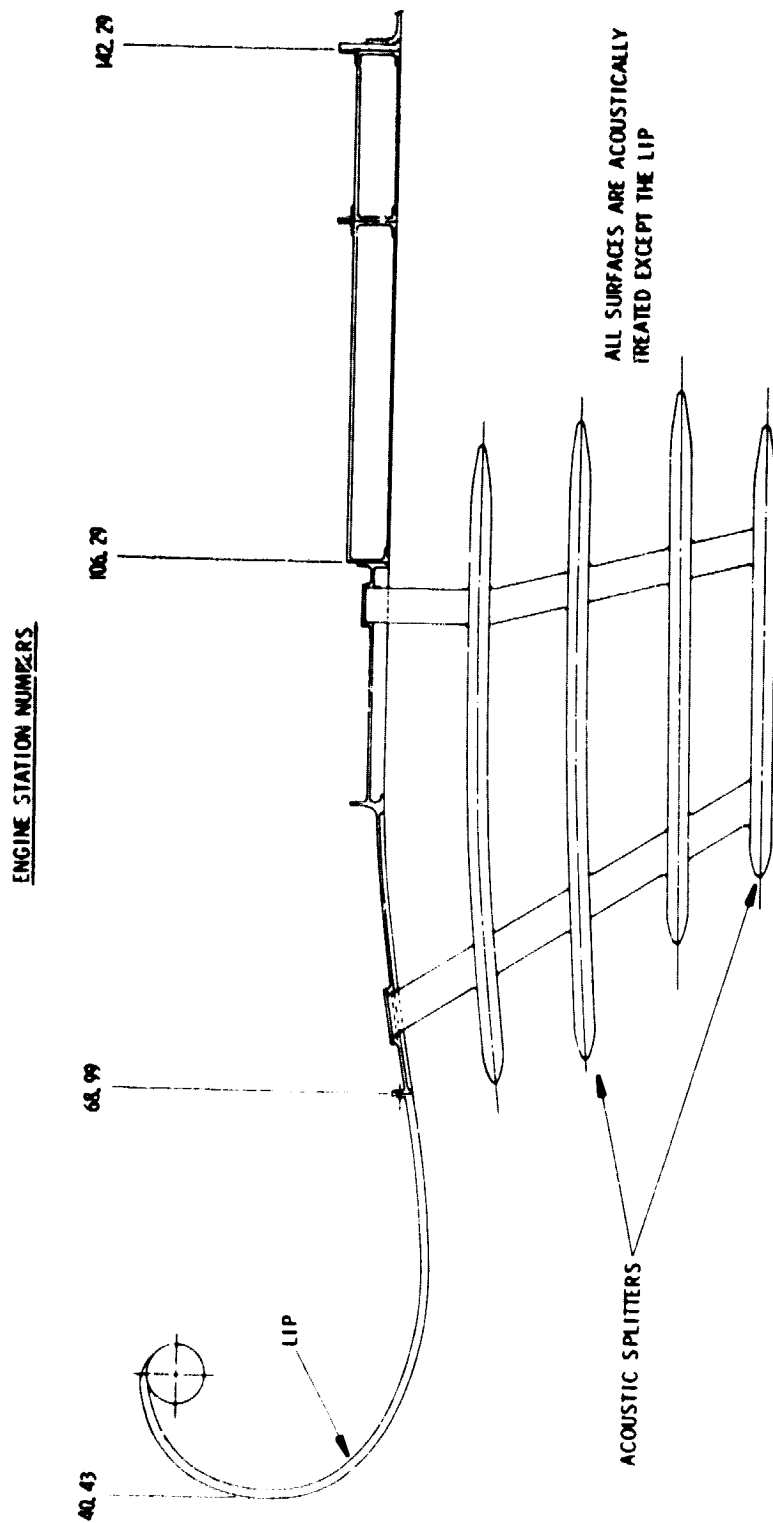


Figure 2. Massive Suppressor Inlet with Four-Ring Splitter.

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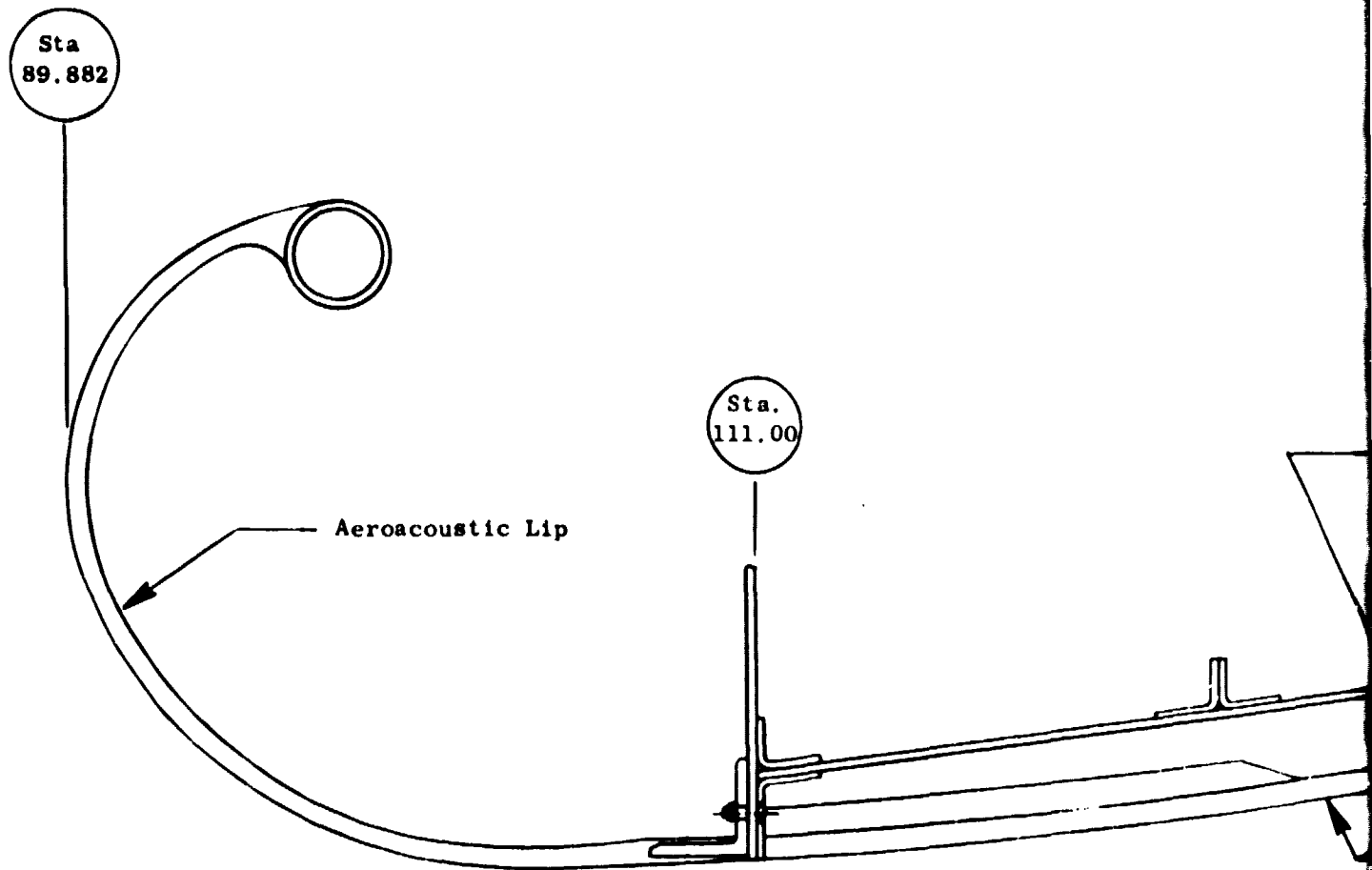
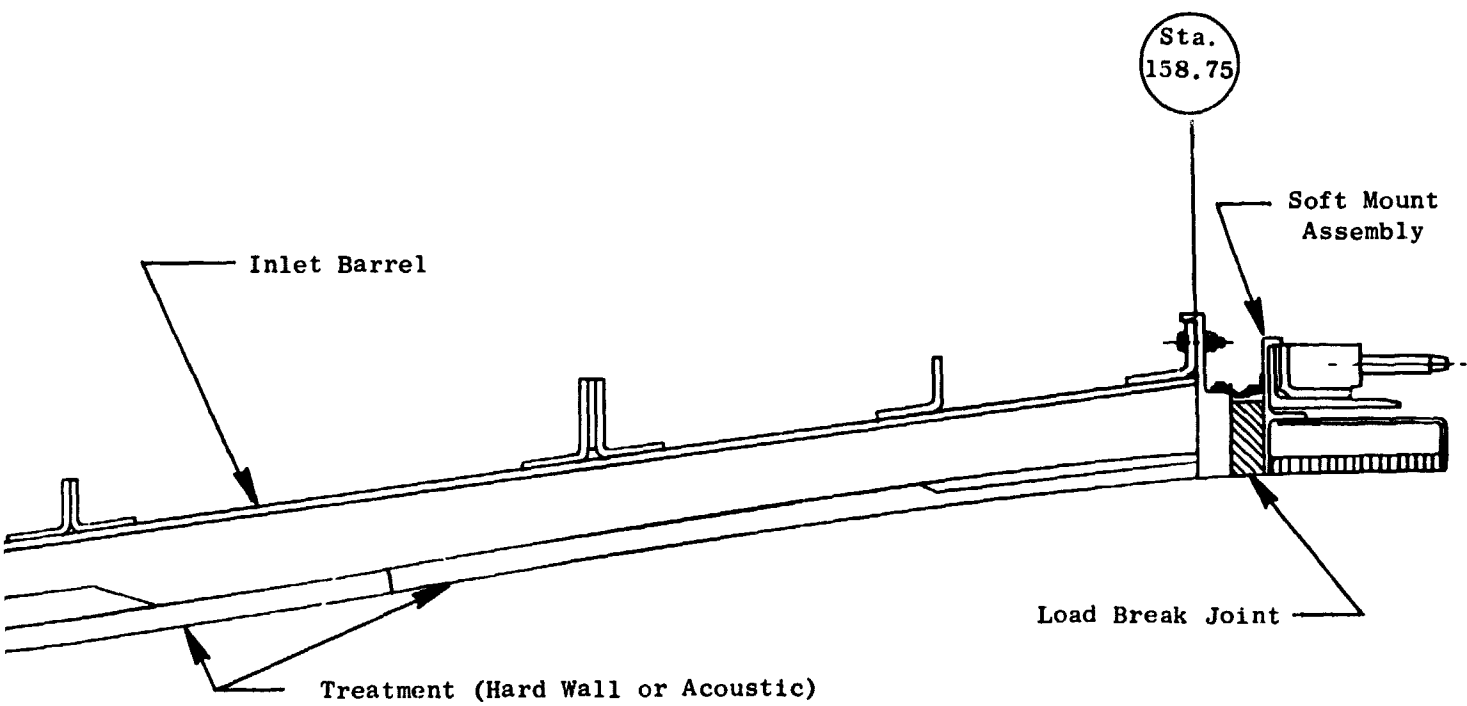


Figure 3. Hybrid Inlet

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Hybrid Inlet Assembly.

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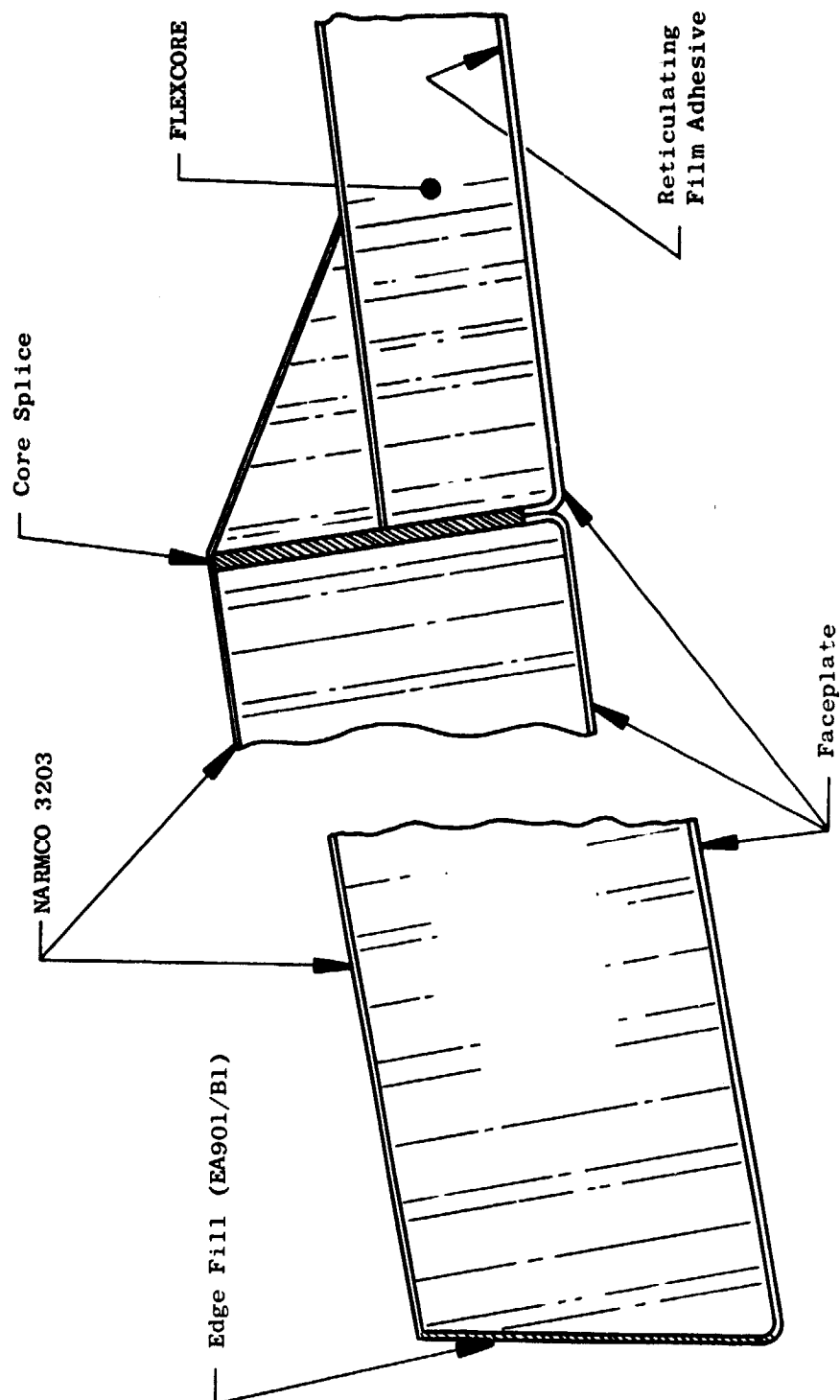


Figure 4. SDOF Acoustic Panel.

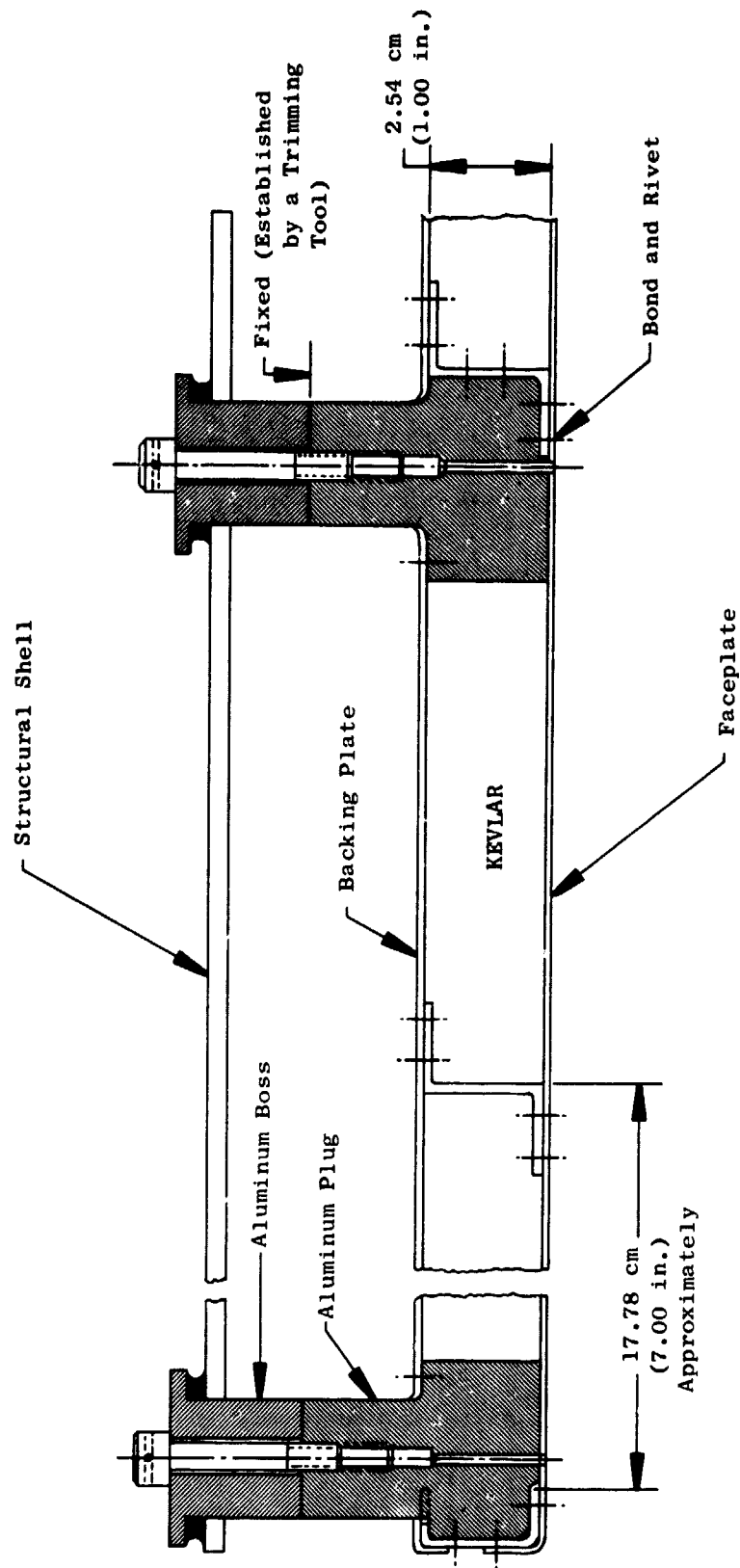


Figure 5. Bulk Absorber Panel.

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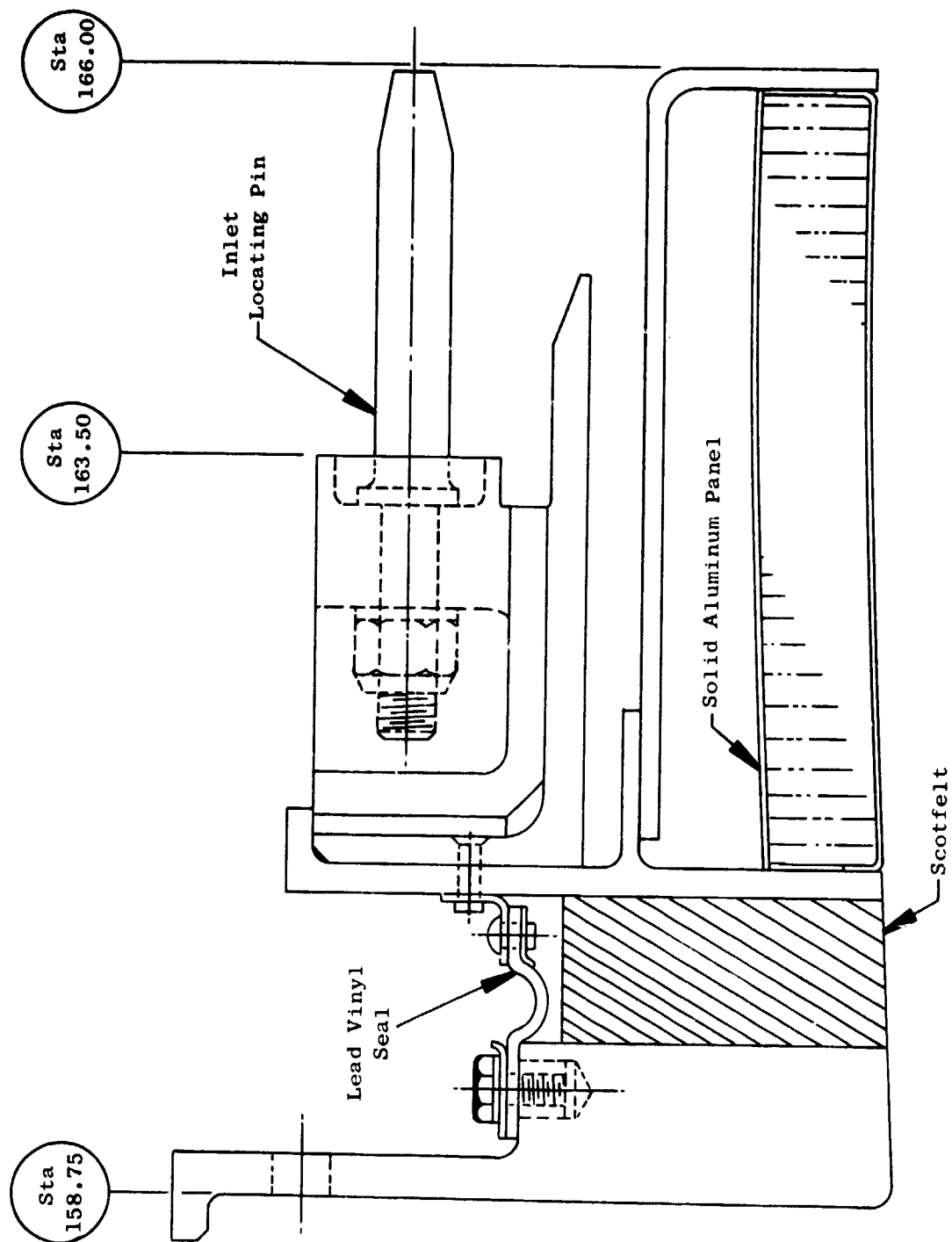


Figure 6. Inlet Decoupling Joint.

## B. FAN COWL

The OTW fan cowl from the composite fan frame to Station 244.5 is an aluminum structural sheet and stringer assembly (Figure 7) that provides the attachment capability for interchangeable sets of acoustic treatment panels. This hardware was procured under the UTW phase of the contract; and, since they share common flowlines in this region of the duct, all of this hardware can be utilized for the OTW program. The fan cowl doors are decoupled from the fan frame to prevent the transmission of excessive nacelle weight to the fan frame. The primary structural attachment is made through two piano-type hinges located at the top edge of the door assemblies. All forward and aft fan cowl loads are transmitted through the hinge to the facility structure. Vertical and side loads are transmitted to the test stand through two telescoping struts which are attached to the door assemblies.

## C. SPLITTER

The acoustic splitter (Figure 8) is a double sandwich structure consisting of aluminum sheet metal skins, machined rings, and honeycomb cores. The leading - and trailing - edge closeouts are aerodynamically machined aluminum rings. The primary load path is carried through the skins and closeout rings, which exemplifies the design intent of all sandwich construction. The final assembly consists of two semicircular structures supported from the fan cowl by six stainless steel airfoil-shaped struts. Silicon seals have been applied to the mating edges of the splitter halves to dampen potential vibratory movement during engine testing.

The splitter is designed to be removable. Filler pieces, which replace the strut feet, will be inserted in the fan doors to provide the capability of engine operation without the splitter. Additional flexibility has been provided through a flange near the trailing edge of the splitter. A second tailpiece has been procured that is capable of converting the 101.6-cm (40-in.) UTW splitter to a 76.2-cm (30-in.) OTW configuration.

## D. CORE COWL

The OTW core cowl (Figure 9) is a stainless steel structural shell that supports interchangeable sets of acoustic or hard wall panels. Since the core cowl flowlines are identical for both UTW and OTW systems, the UTW acoustic and hard wall panels can be utilized in the OTW system. The core cowl has a forward interface (Marman-type joint) with the fan frame, and an aft interfacing slip joint with the core nozzle. Access to the compressor and turbine is provided by the hinged-door construction of the core ducting. Prior to the opening, the core doors and apron assembly are temporarily attached to and supported by the pylon through a set of pins.

The core cowl will employ shop-air cooling, bleed air from the fan duct, and radiation shields to maintain a safe operating environment for the epoxy resins that will be used in the construction of the acoustic and hard wall panels.

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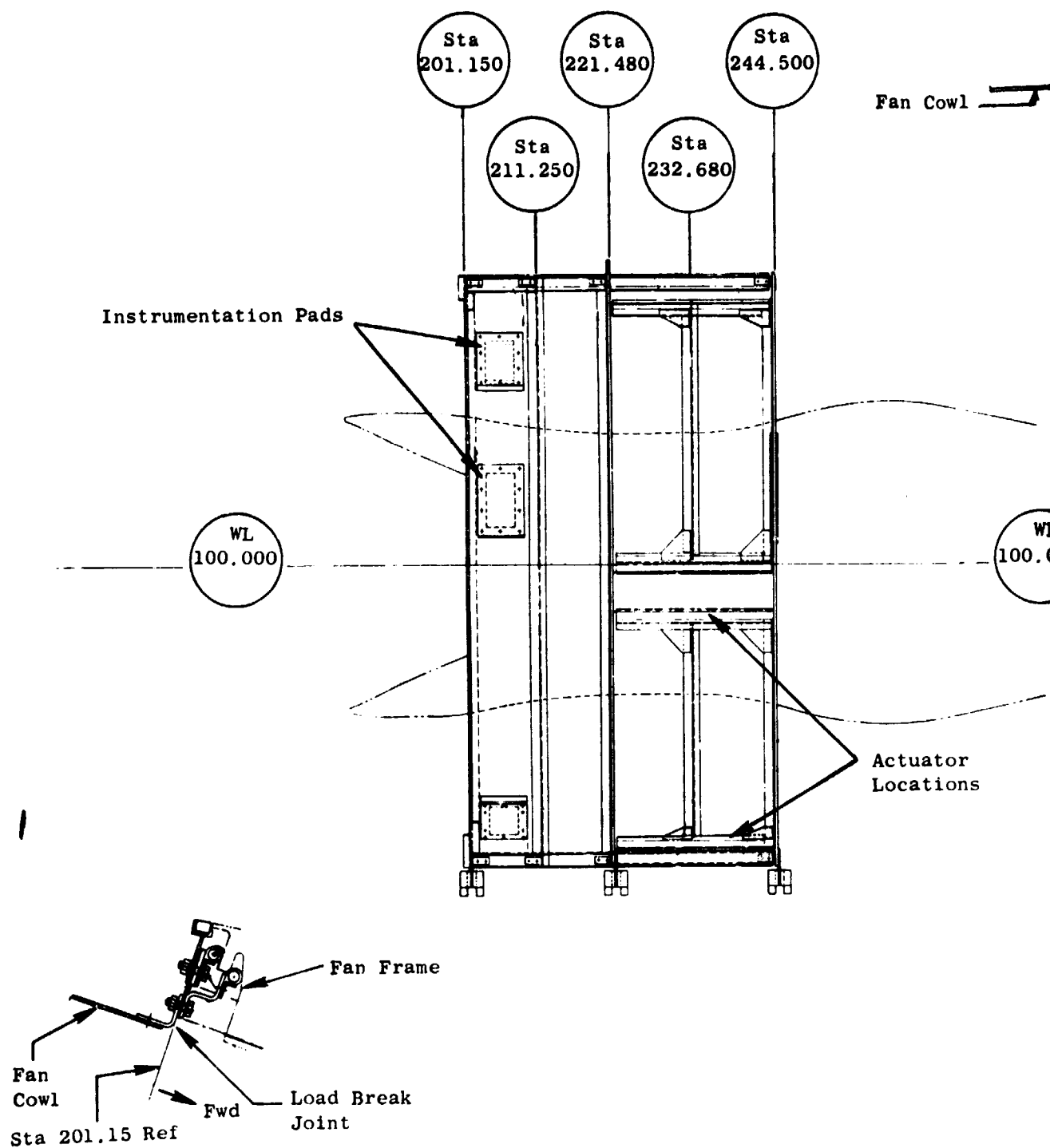
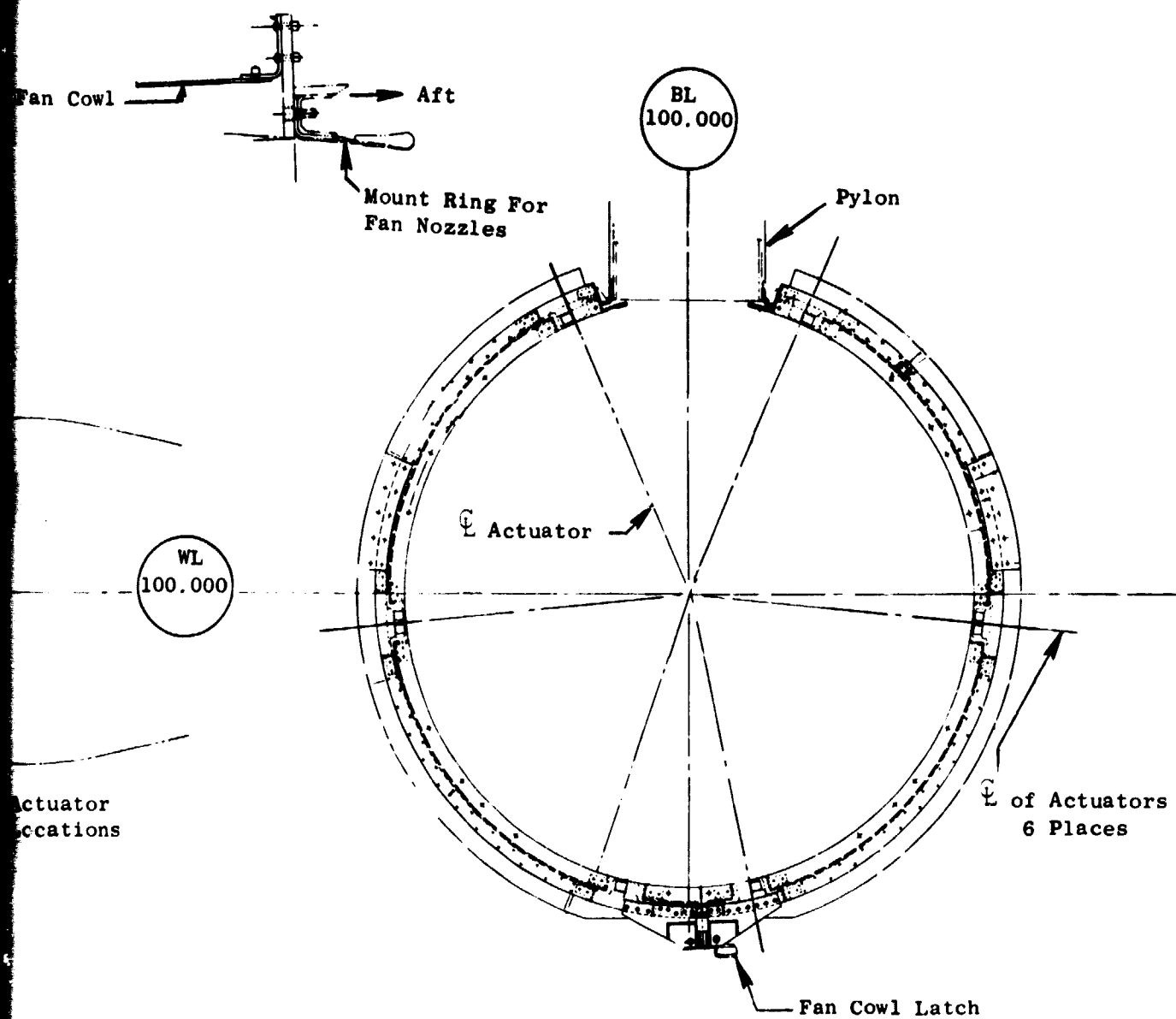


Figure 7. Fan Door



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Figure 7. Fan Doors.

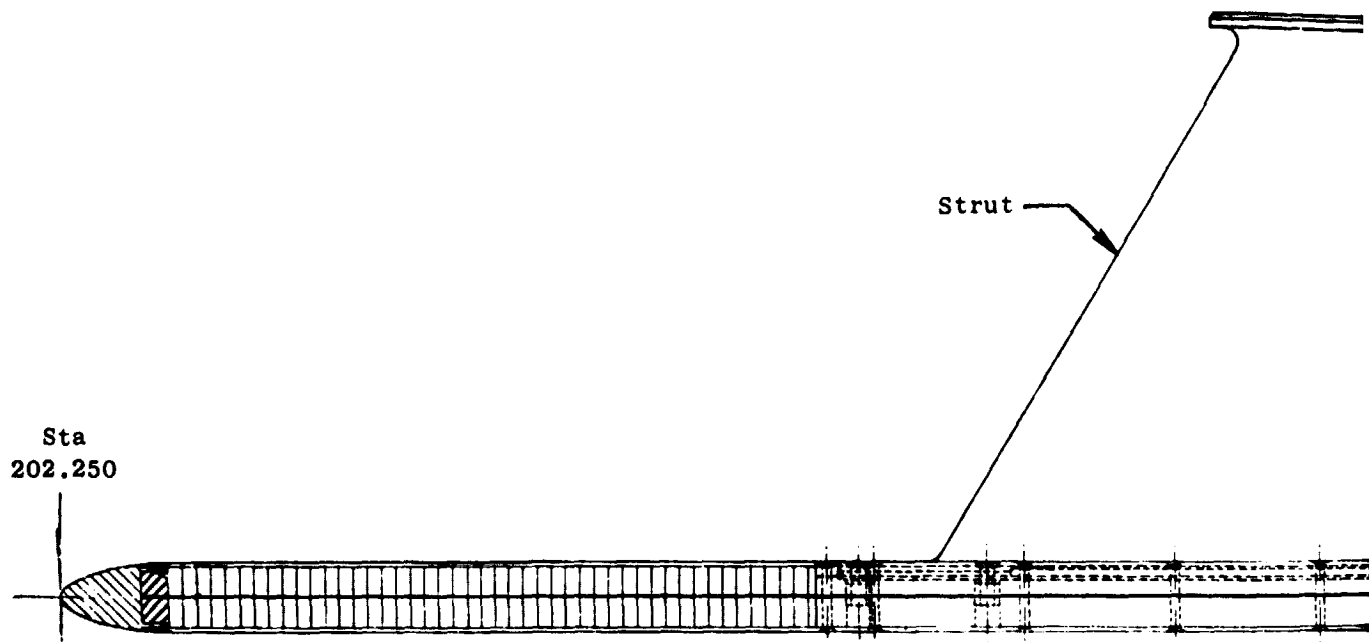
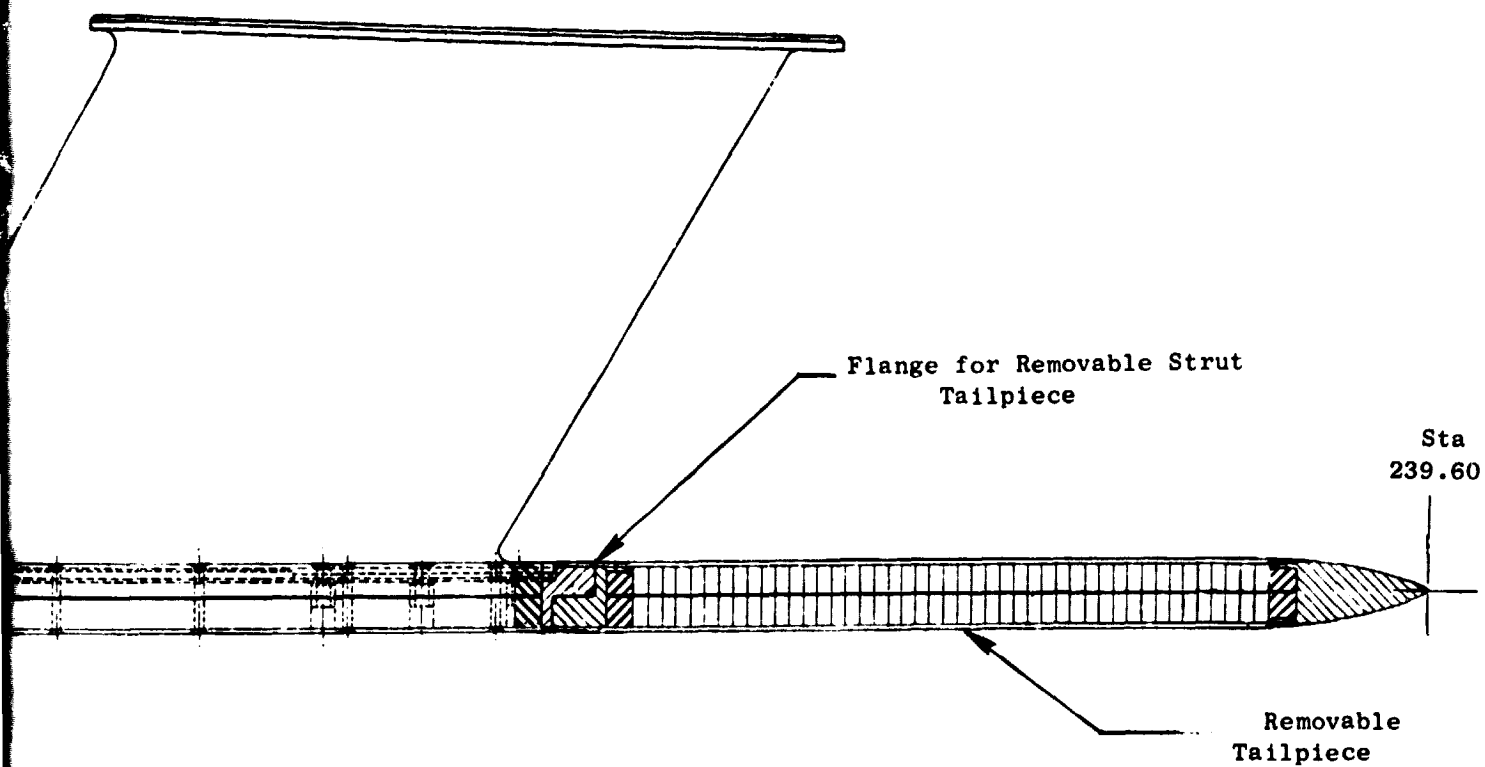


Figure 8. Splitter As

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8. Splitter Assembly.

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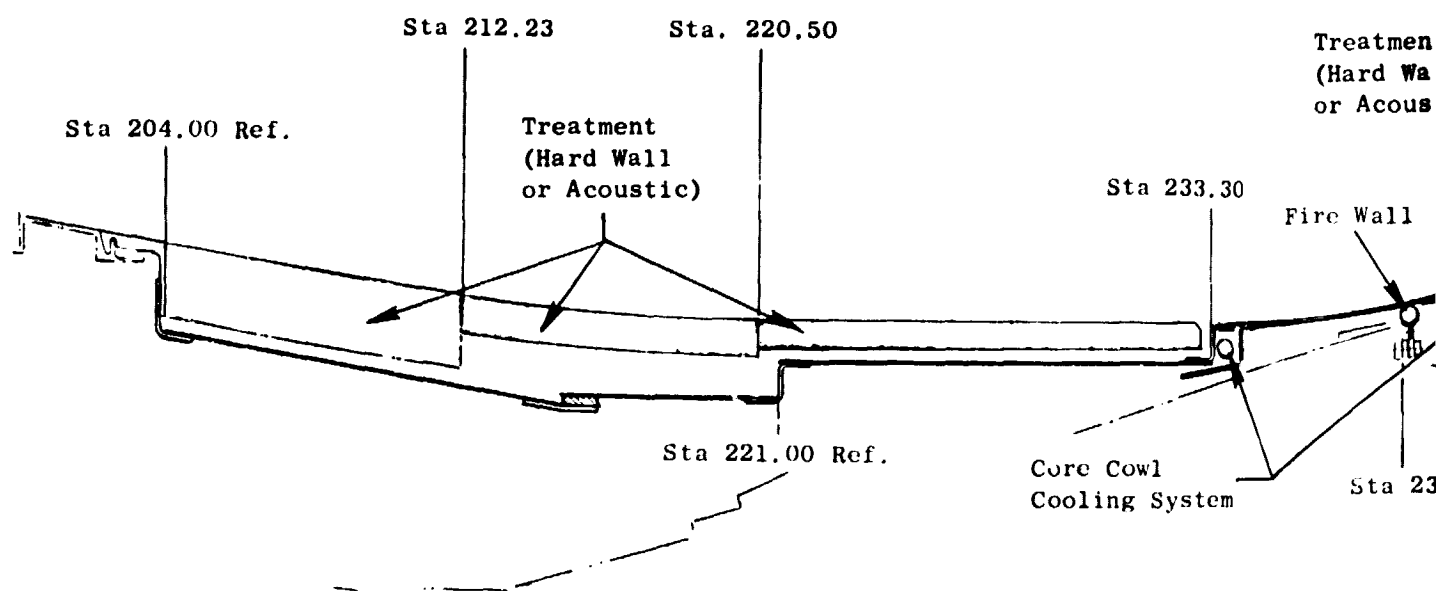
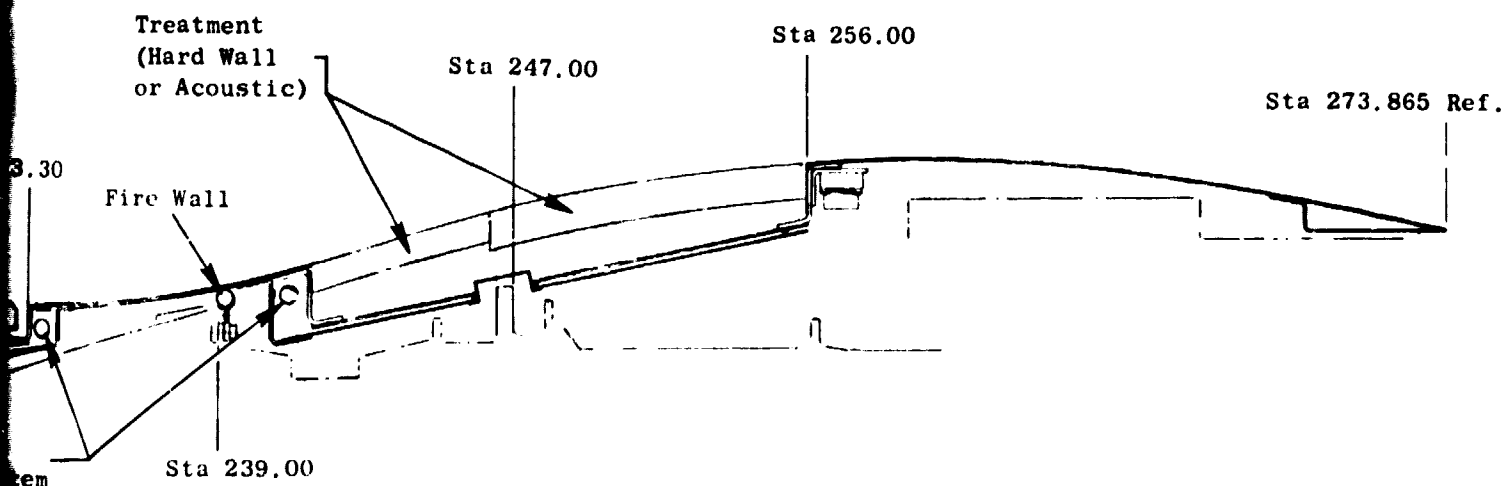


Figure 9. Core Cowl A

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9. Core Cowl Assembly.

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E. PYLON

The pylon assembly is the primary structural support system for the fan exhaust duct assembly. It is bolted to the engine mount system, transmitting fan cowl loads directly to the facility. The inner skirt and hinge are decoupled from the pylon during engine operation and attached to the pylon when the doors are open. Core door loads are transmitted to the fan frame during engine testing. The pylon upper support assembly and boattail assembly are hard-mounted to the test stand structure. The aluminum fairings that make up the pylon forward assembly are attached to the low carbon steel pylon upper support structure through structural fasteners. The pylon fairings have 35.56- x 76.20-cm (14- x 30-in.) removable access panels on both sides and provide the aerodynamic contour of the pylon. The removable fairings provide accessibility for core instrumentation inspection (Figure 10).

In addition to the structural attachment to the facility, the pylon upper support structure and forward assemblies have interfaces with the fan cowl through piano-type hinges at the top of the fan cowl door assemblies, with the splitter assembly through a seal along its top edges, and with the apron assembly through a fillet seal at the lower edge of the pylon.

F. ACOUSTIC PANELS

1. Single Degree of Freedom (SDOF)

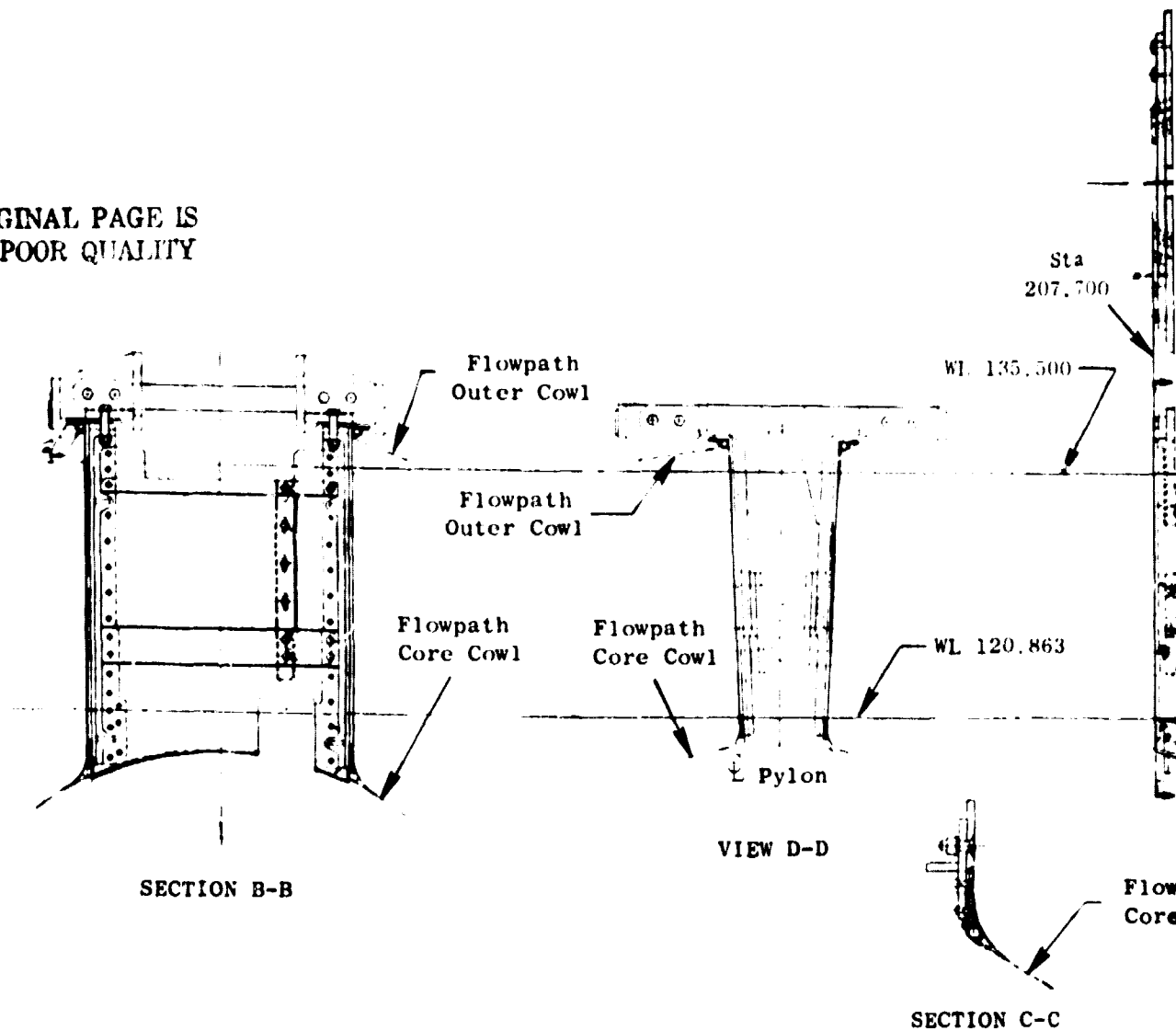
All SDOF and hard wall panels (Figure 4) are similar in design. The difference between the hard wall panels and the treated panels is the substitution of a hard face sheet for a perforated face sheet. All the materials used for the panels have 450 K (350° F) capability.

2. Bulk Absorber - Kevlar

The design and construction of these panels are shown in Figure 5. The panels were fabricated from the SDOF tooling except for the "Z"-section stiffeners which required some contour tooling. One set of inlet panels is available for OTW engine testing.

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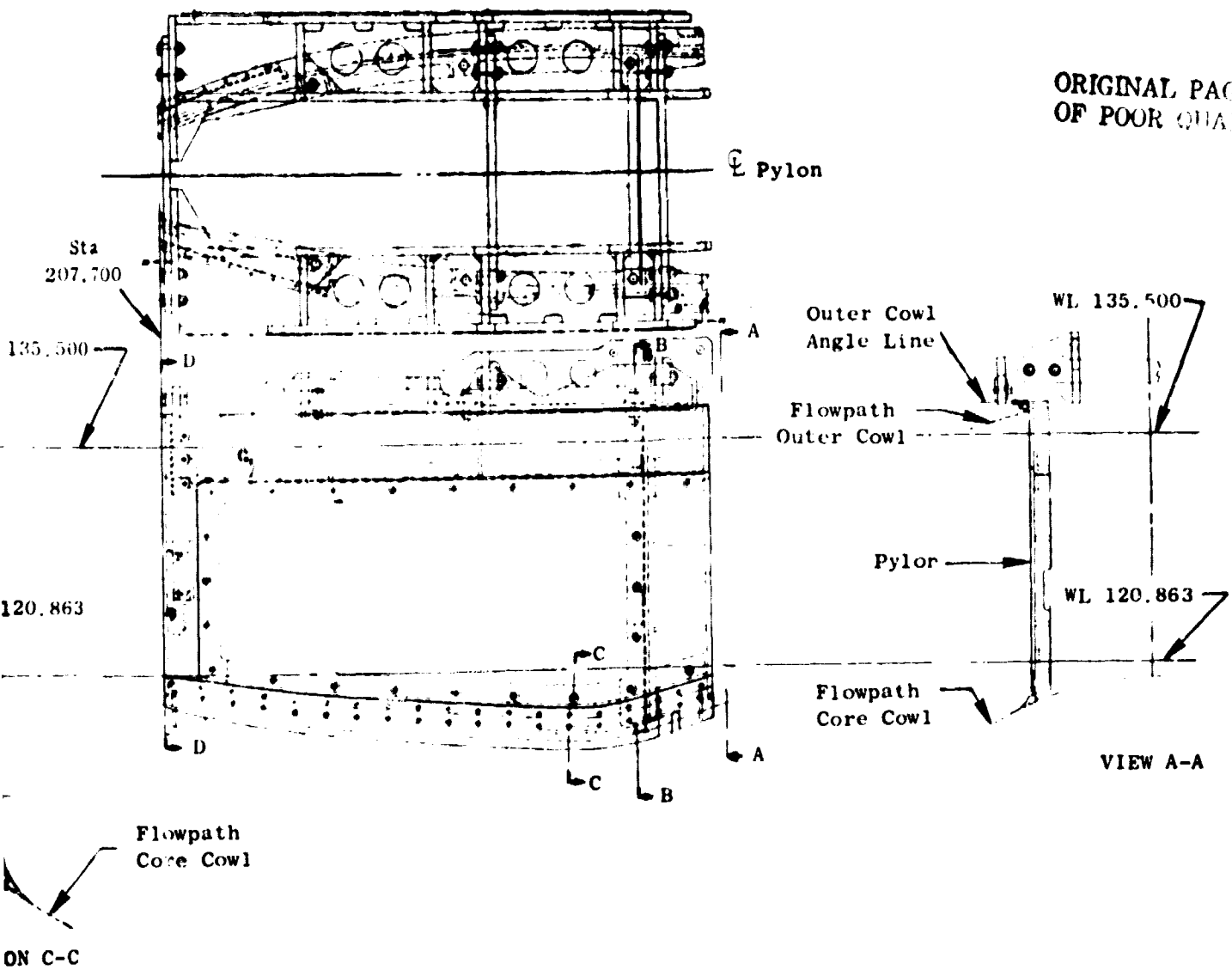
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Figure 10. Forward Pylon Assembly and

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ion Assembly and Upper Support Structure.

### SECTION III

#### NACELLE DESCRIPTION - OTW HARDWARE

This section describes the hardware that was designed and fabricated to complete the conversion of the OTW hardware into an OTW configuration.

##### A. FAN COWL EXTENSION

The OTW fan cowl extension is an aluminum structural sheet and stringer assembly consisting of two semicircular door structures that are supported by the UTW fan cowl door assemblies at Station 244.5. They provide the attachment capability for interchangeable sets of acoustic treatment and hard wall panels from Station 244.5 to Station 262. Station 262 represents the last circular section and the end of the acoustic treatment. It is also the plane of rotation for the thrust reverser which will be clocked 90° during NASA testing. The complete fan cowl extension with hard wall panels is shown later in Figure 27.

##### B. SPLITTER

A new splitter tailpiece has been provided to convert the 101.6-cm (40-in.) UTW splitter to a 76.2-cm (30-in.) configuration that is required by the OTW engine (Figures 8 and 11).

The fabrication procedure for the splitter trailing edge follows: after the aluminum rings have been riveted and bonded with EA 901/B1 (Hysol Corporation) to the inner aluminum perforated faceplate, it is positioned in the tool as shown in Figure 12.

Hexabond adhesive, a product of Hexcel Corporation, is applied to one side of the honeycomb (Hexcel CPHIII - 1/4 - 5052) with an adhesive weight of 0.088 to 0.107 kg/m<sup>2</sup> (0.018 to 0.022 lb/ft<sup>2</sup>). The Hexabond adhesive, which is always placed on the faceplate side, provides good strength characteristics for its weight with essentially no hole plugging. After the honeycomb is trimmed and positioned, the ring closeouts are filled with a core splice adhesive per GE Specification P6TF1, and the middle septum plate is bonded to the honeycomb with Metalbond 329 supported film adhesive. This assembly is cured under pressure before proceeding.

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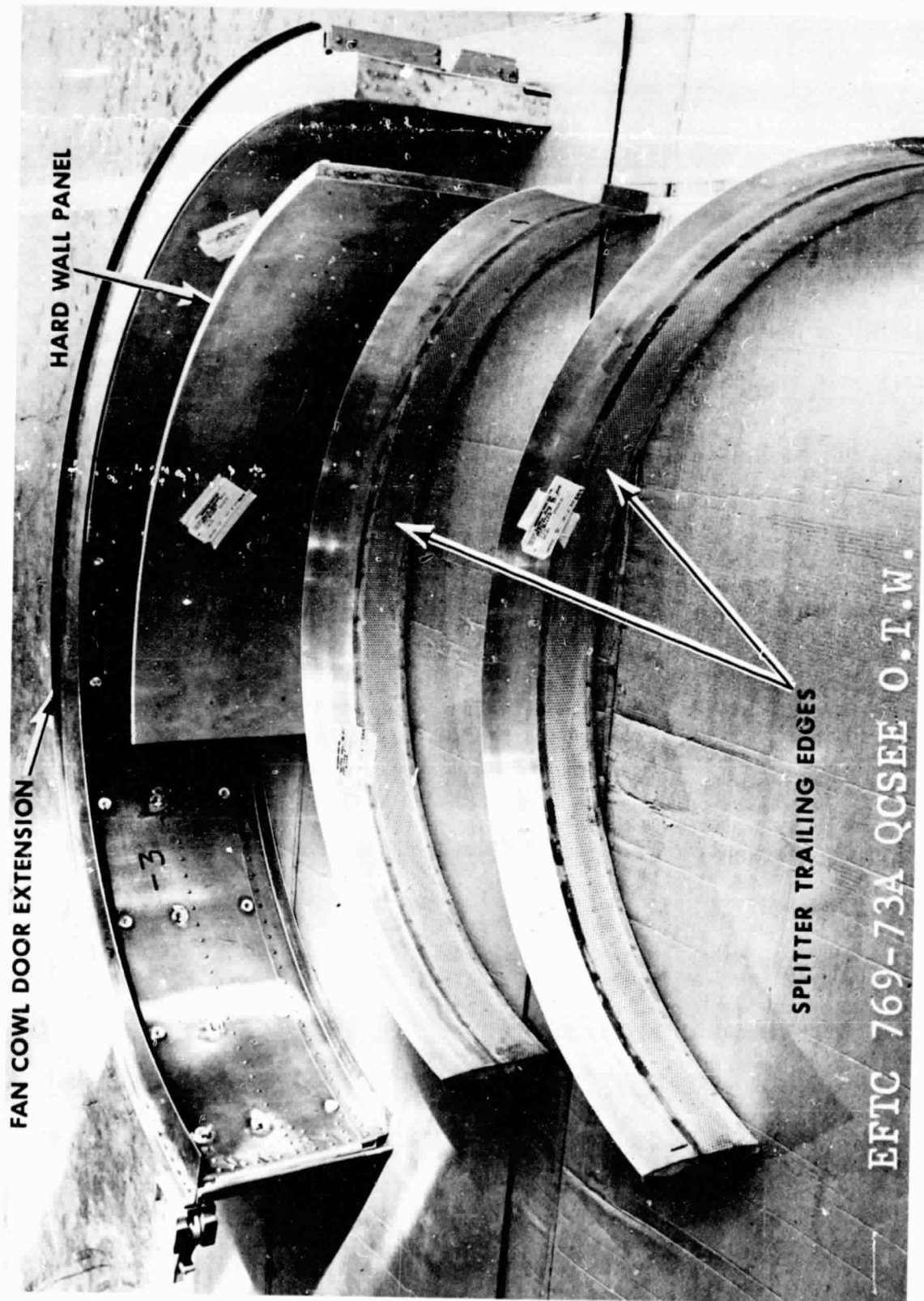


Figure 11. Splitter Trailing Edges and One of the Fan Cowl Door Extensions.

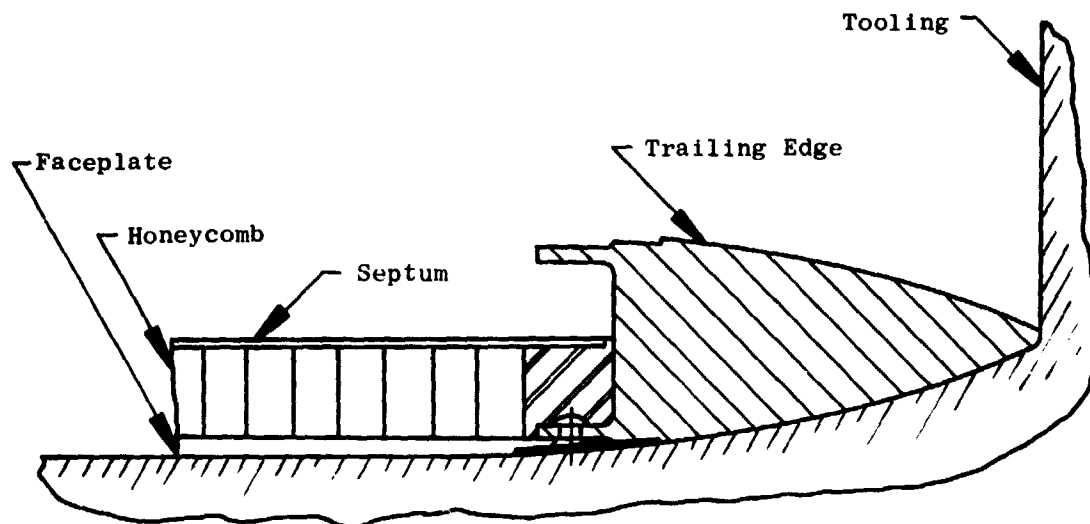


Figure 12. Splitter Tooling Schematic.

The next step is to assemble the outer sandwich structure in a manner similar to that described above, but in reverse order. Following this second bonding operation, the part is removed from the tool (Figure 13).

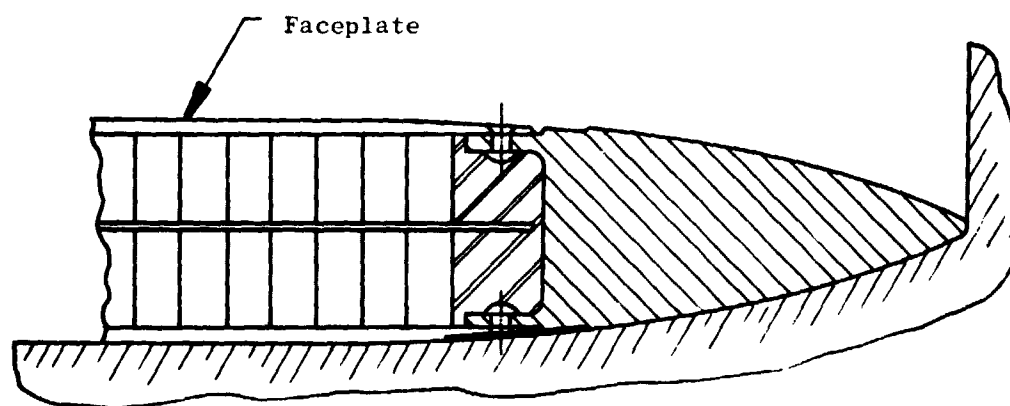


Figure 13. Splitter Tooling Schematic/Final Operation.

The final operation is to cover all exposed rivet heads. This is accomplished by bonding thin strips of 181-gage fiberglass cloth impregnated with adhesive around all of the closeouts (Figure 14).

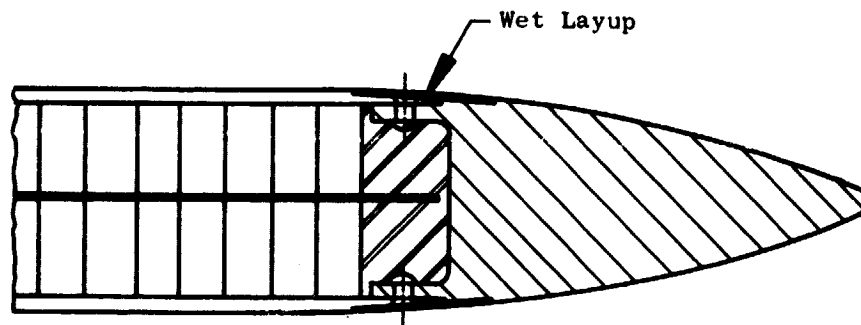


Figure 14. Splitter Complete.

### C. ACOUSTIC PANELS

#### 1. Single-Degree-of-Freedom Process Changes

Within the scope of the OTW program, there is a possibility that more acoustic panels will be procured. Acoustic evaluation of the OTW engine may reveal a need to define new faceplate porosities and/or treatment depths. If the acoustic requirements demand new panels, a revised fabrication plan has been formulated to eliminate the Hexabond adhesive from the cycle and to replace it with an alternative.

A typical SDOF acoustic panel cross section is shown in Figure 4. All of the panels are fabricated from a tool simulating the flowpath. The face sheets are stretch-formed to the final contour to reduce residual stress that may exist between the face sheet and core material after curing and to provide a smooth contour. The core material is Hexcel aluminum Flexcore (5052/F40), and it is preferred for its favorable contouring characteristics over standard honeycomb in double-curvature applications.

The inlet and fan door panels are processed in a single cure cycle. The adhesive used between the faceplate and the Flexcore is Metalbond 328. This is a reticulating, unsupported film adhesive. The film adhesive is laid over the Flexcore, and a heat gun is applied to reticulate the adhesive. The heat causes the film adhesive to break between cells and to collect on the foil ridges of the Flexcore. Utilization of this characteristics of a reticulating adhesive prevents plugging of the perforated holes in the faceplate. Following the application of the Metalbond 328, the faceplate is placed on the tool and the pretrimmed Flexcore is positioned over it. Three plies of NARMCO 3203 prepreg cloth then are wrapped over the assembly with core splicing between core sections and edge fill around the edges. The entire assembly is cured under pressure.

For the core doors, the NARMCO 3203 prepreg is replaced with FERRO E293 prepreg, and one ply of Metalbond 329 supported film adhesive is added between the E293 and the Flexcore to improve the adhesive characteristics of this particular prepreg.

#### D. "D"-SHAPED EXHAUST NOZZLE AND THRUST REVERSER

##### 1. Transition Section and Pylon Closeouts

The OTW transition section, from Stations 262 to 290, features an aluminum structural sheet and stringer assembly that is decoupled from the fan door system and provides the aerodynamic section that transitions from circular cross sections to the "D"-shaped nozzle assembly. The decoupled joint is shown in Figure 15, and the transition section is shown in Figure 16.

This section will accommodate the Peebles testing and the 1.57 radians (90°) rotational requirement for NASA testing. This is accomplished through two separate pylon closeout sections that are contoured to fit their respective positions (Figures 17 and 18). In both cases, this structural shell is supported from the thrust reverser which utilizes its own mount system.

##### 2. "D"-Shaped Nozzle

The "D"-shaped nozzle assembly is a structural fabrication comprised of stainless steel contoured shells and rings that provides multipositional fan nozzle area control and a "two"-position thrust reverser (Figures 19, 20, and 21). Interface provisions will allow NASA to adapt a wing segment for Lewis testing. The fan area control is maintained by two multipositional side doors and is accomplished by making adjustments during engine shutdown. The "two"-position thrust reverser will be bolted in either the closed or "full-open" position. The "full-open" position, however, is actually two positions, because adapters have been provided to accommodate a 1.05-radians (60°) and 1.22-radians (70°) rotation of the blocker door. Bolt-on sideplates and lip extensions will simulate the configuration of the flight reverser in its fully deployed position. This assembly incorporates its own mount system and will accommodate either the Peebles test system or the NASA 1.57-radians (90°) rotated test position.

Fabrication of the "D"-shaped cross sections was accomplished by stretch-forming stainless steel skins and reinforcing those skins with contoured rings (Figure 22 shows the primary tool used for stretch forming). Figure 23 and 24 show various stages of the fabrication process and how the tool was utilized to assemble the multiple stretch-form pieces. Figures 20 and 21 show the final assembly of the "D"-shaped nozzle.

The thrust reverser is decoupled from the engine and supported through a facility-supplied mount system. The structure has four mounting clevises,

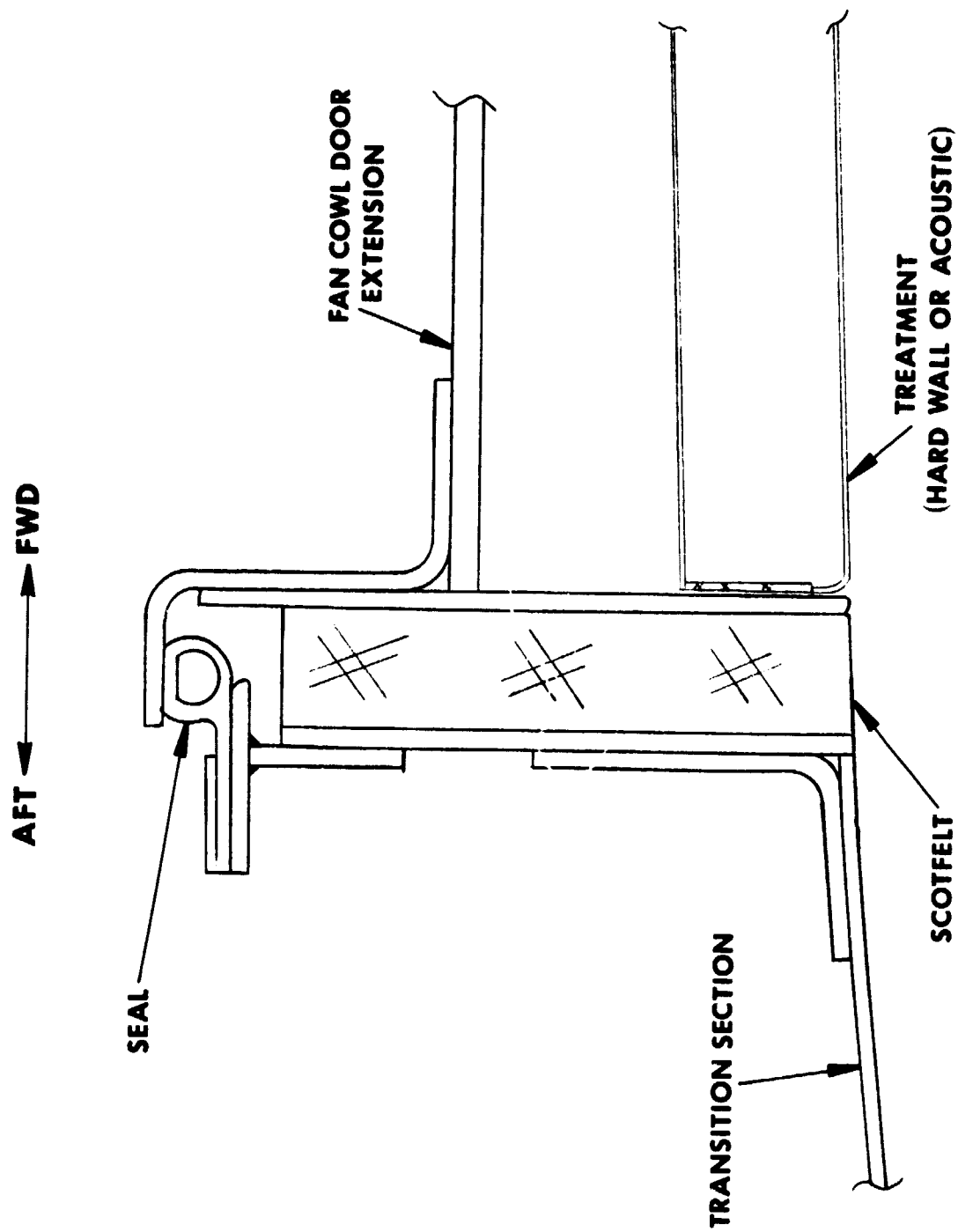


Figure 15. "D"-Shaped Nozzle Decoupled Joint.

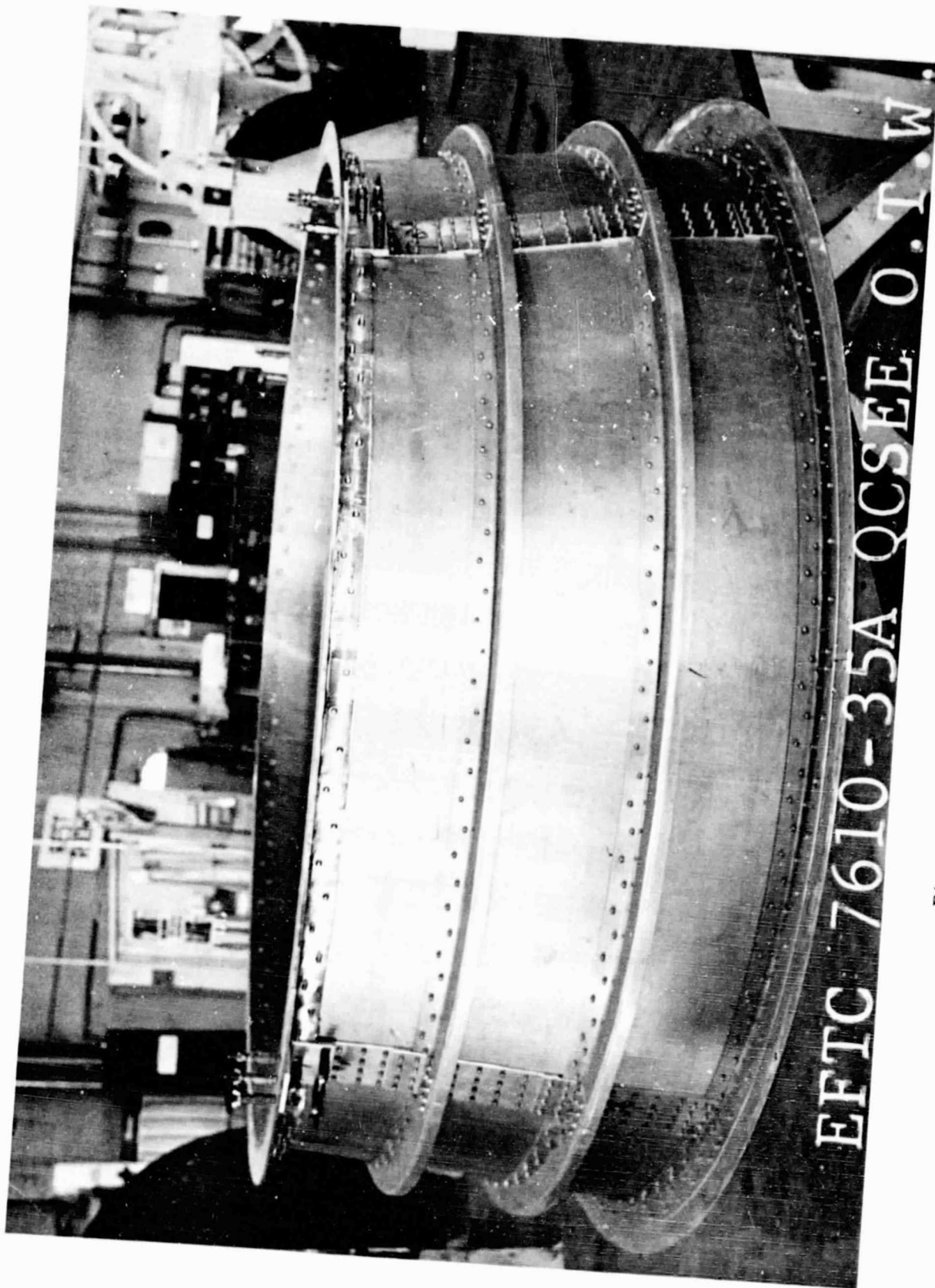


Figure 16. Transition Assembly.

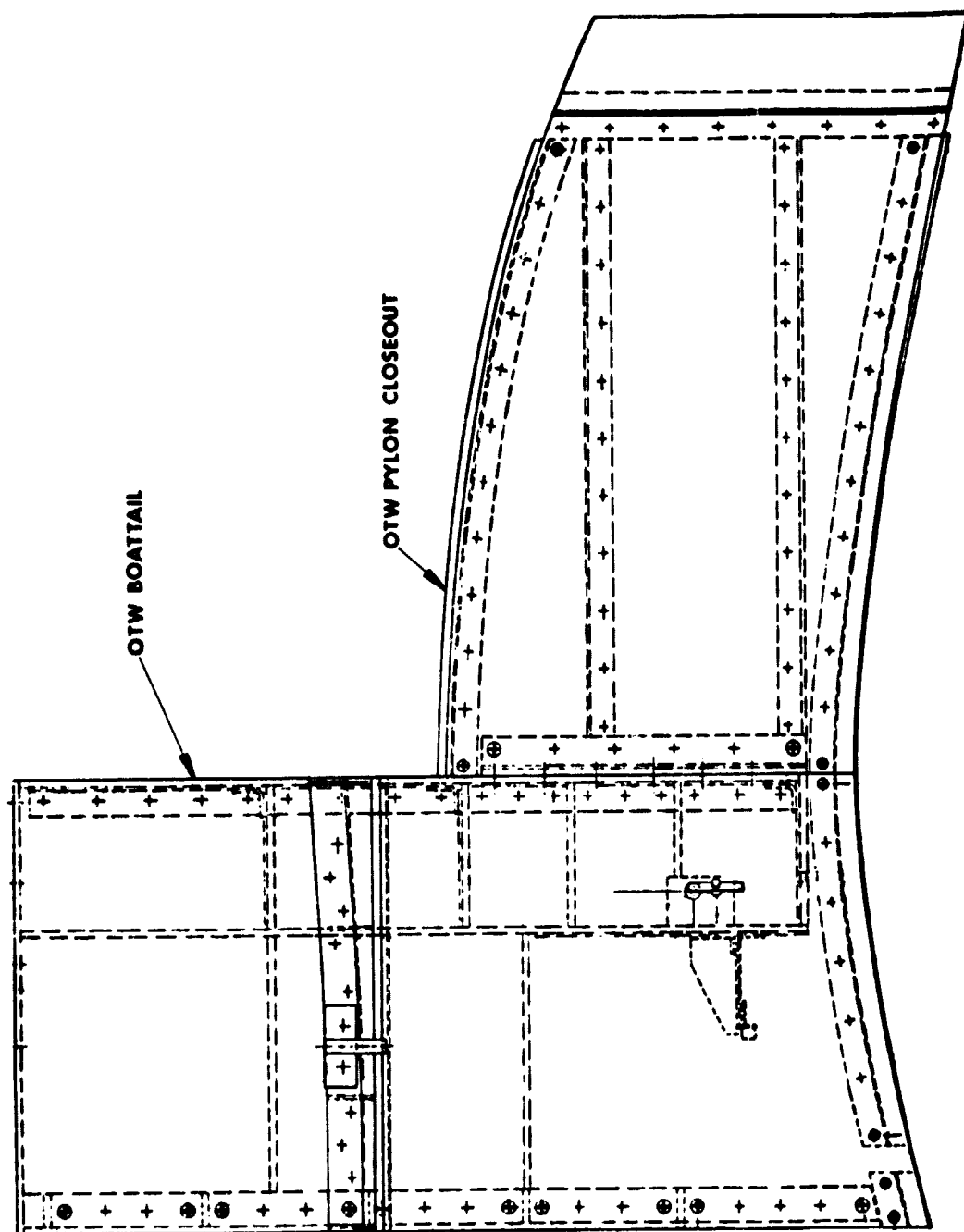


Figure 17. OTW Pylon Closeout Assembly.

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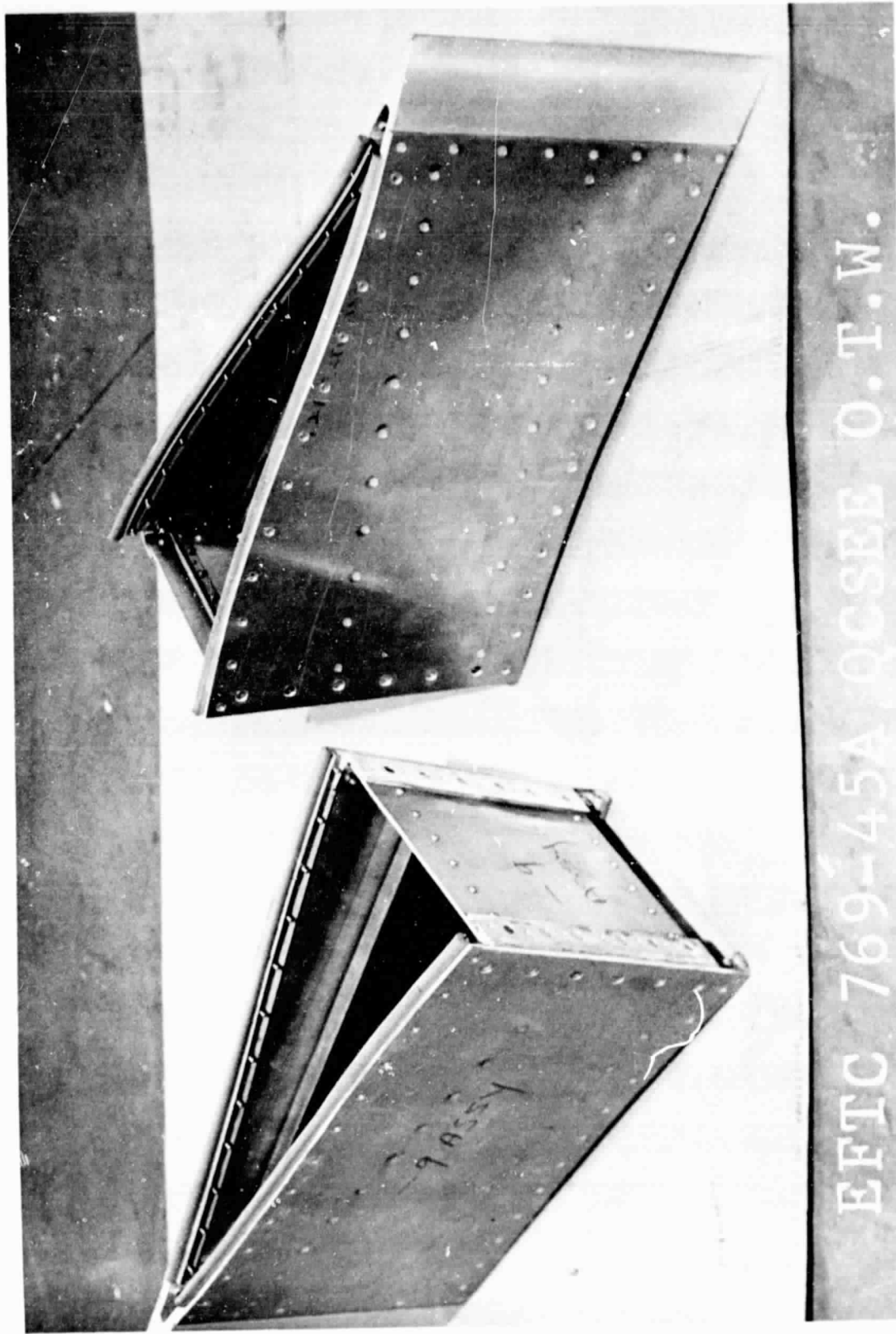


Figure 18. OTW Pylon Closeout for Peebles and NASA-Lewis.

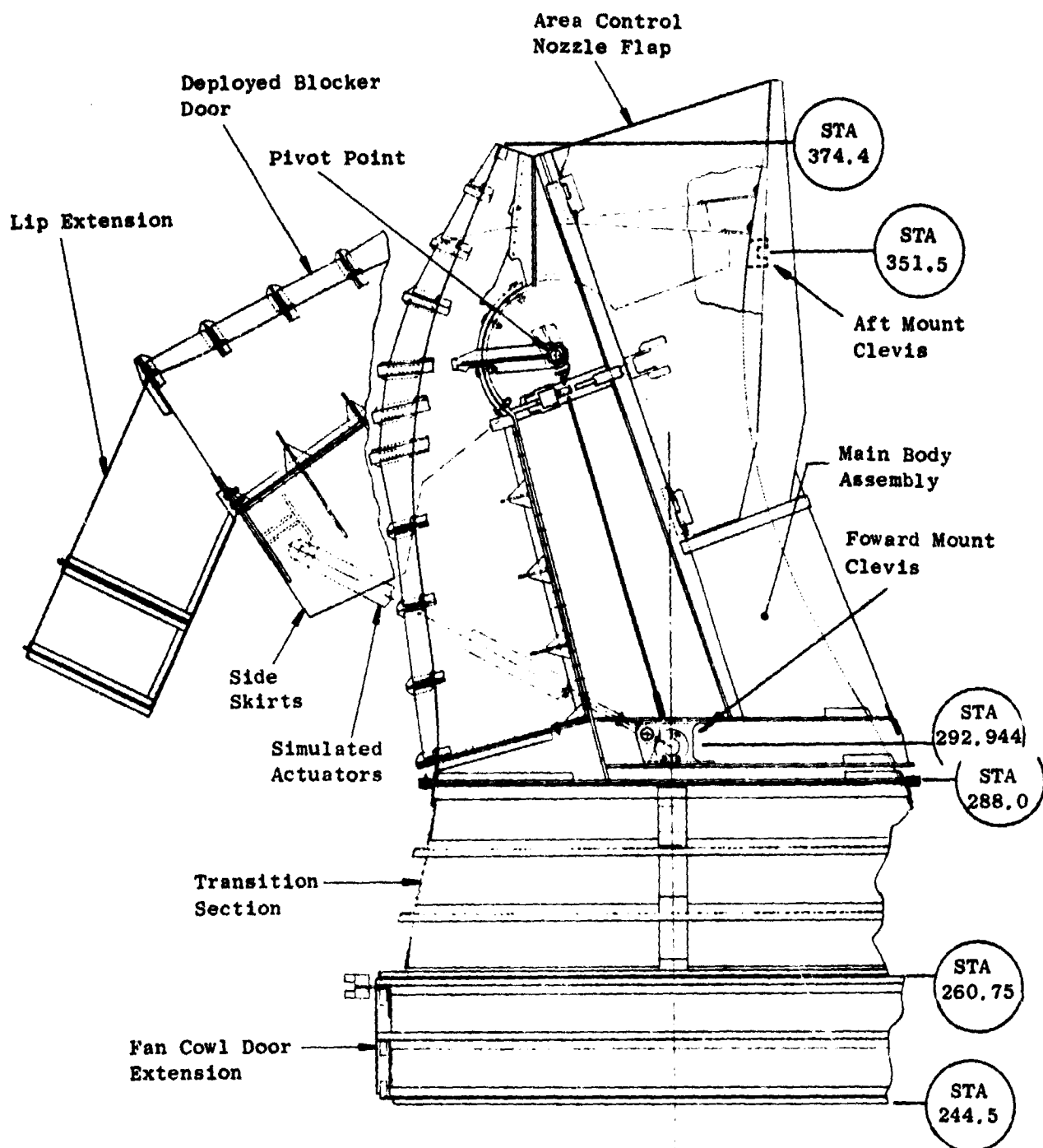


Figure 19. "D"-Shaped Nozzle Assembly Schematic.

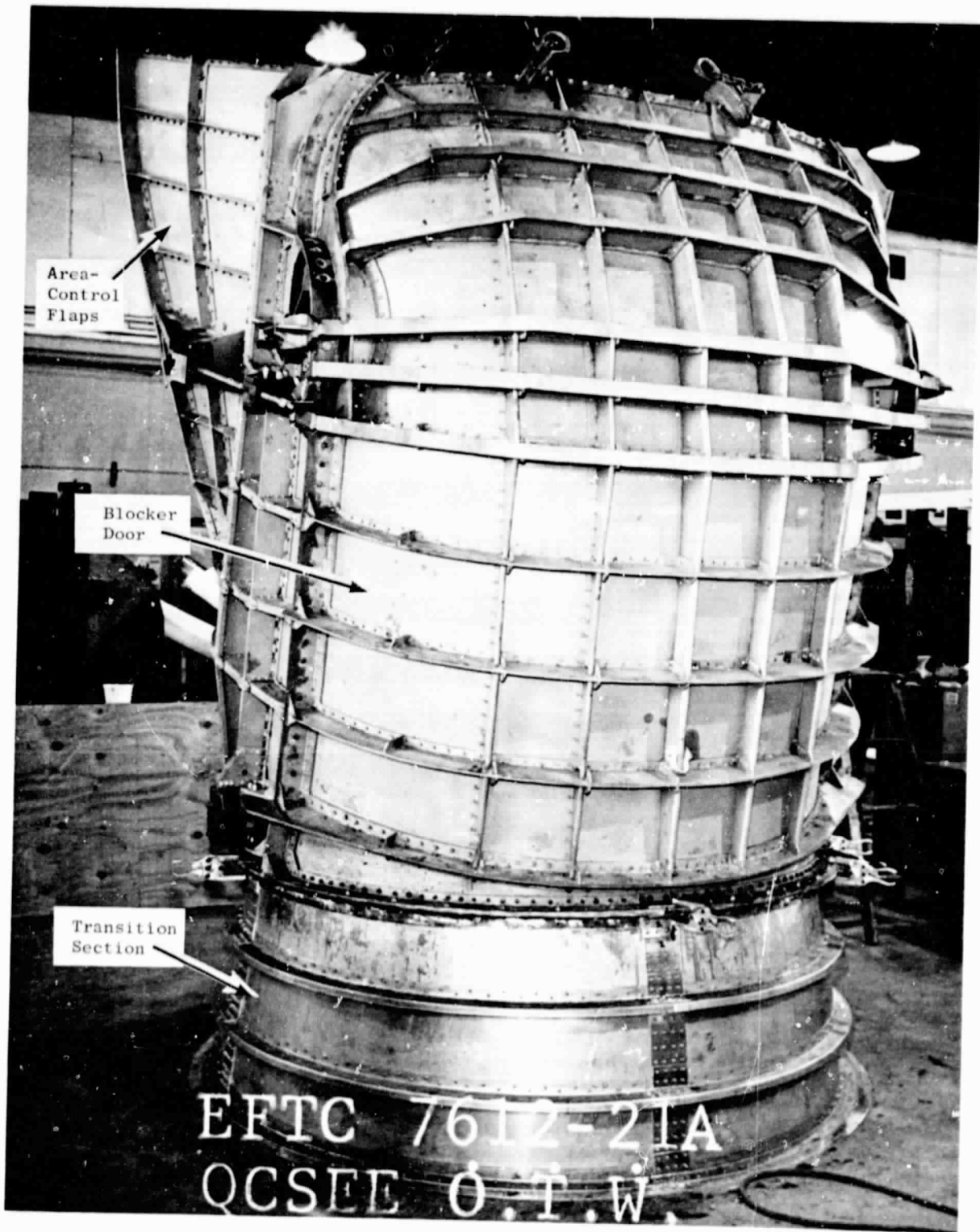


Figure 20. "D"-Shaped Nozzle Assembly.

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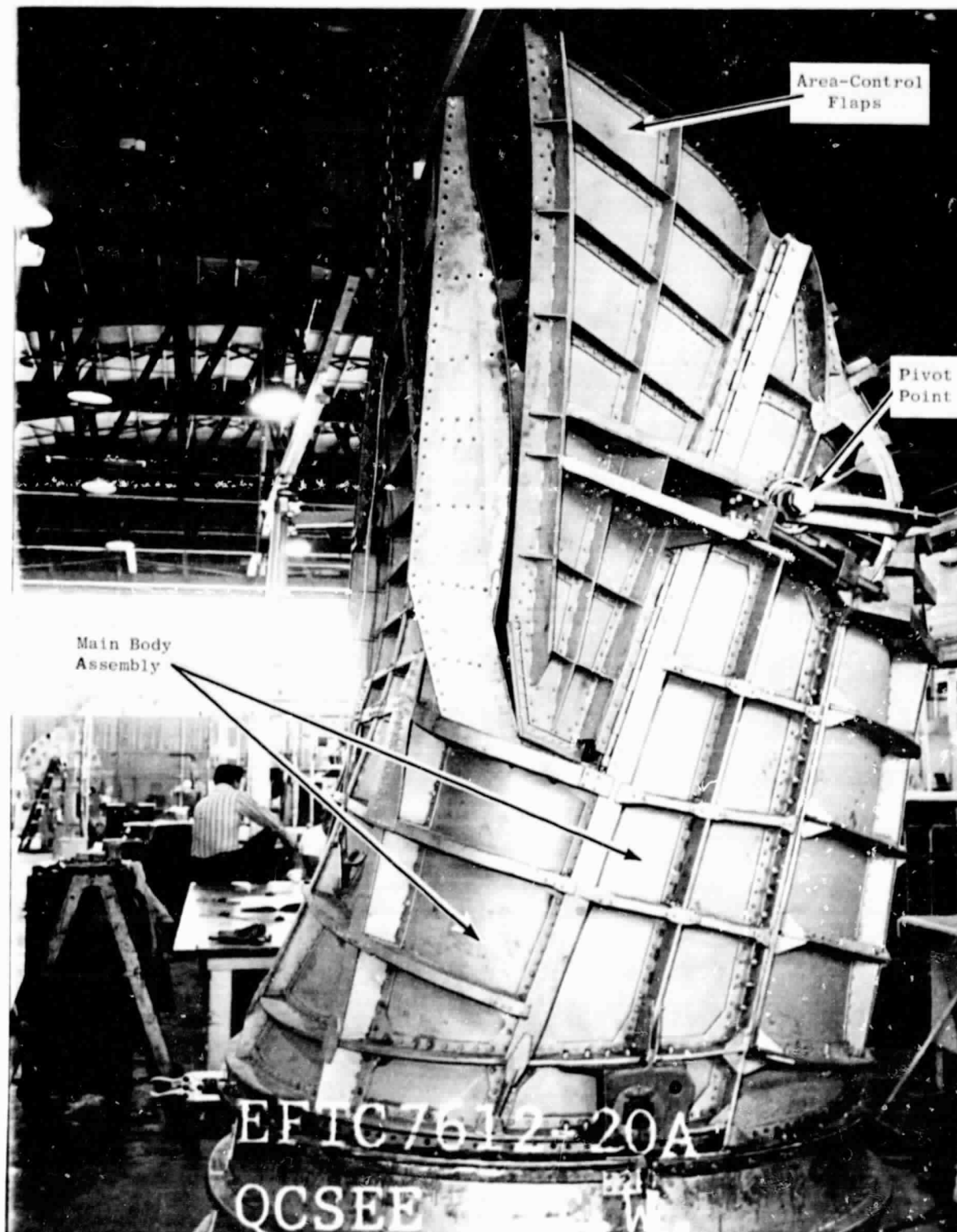


Figure 21. "D"-Shaped Nozzle Assembly - Sideview.

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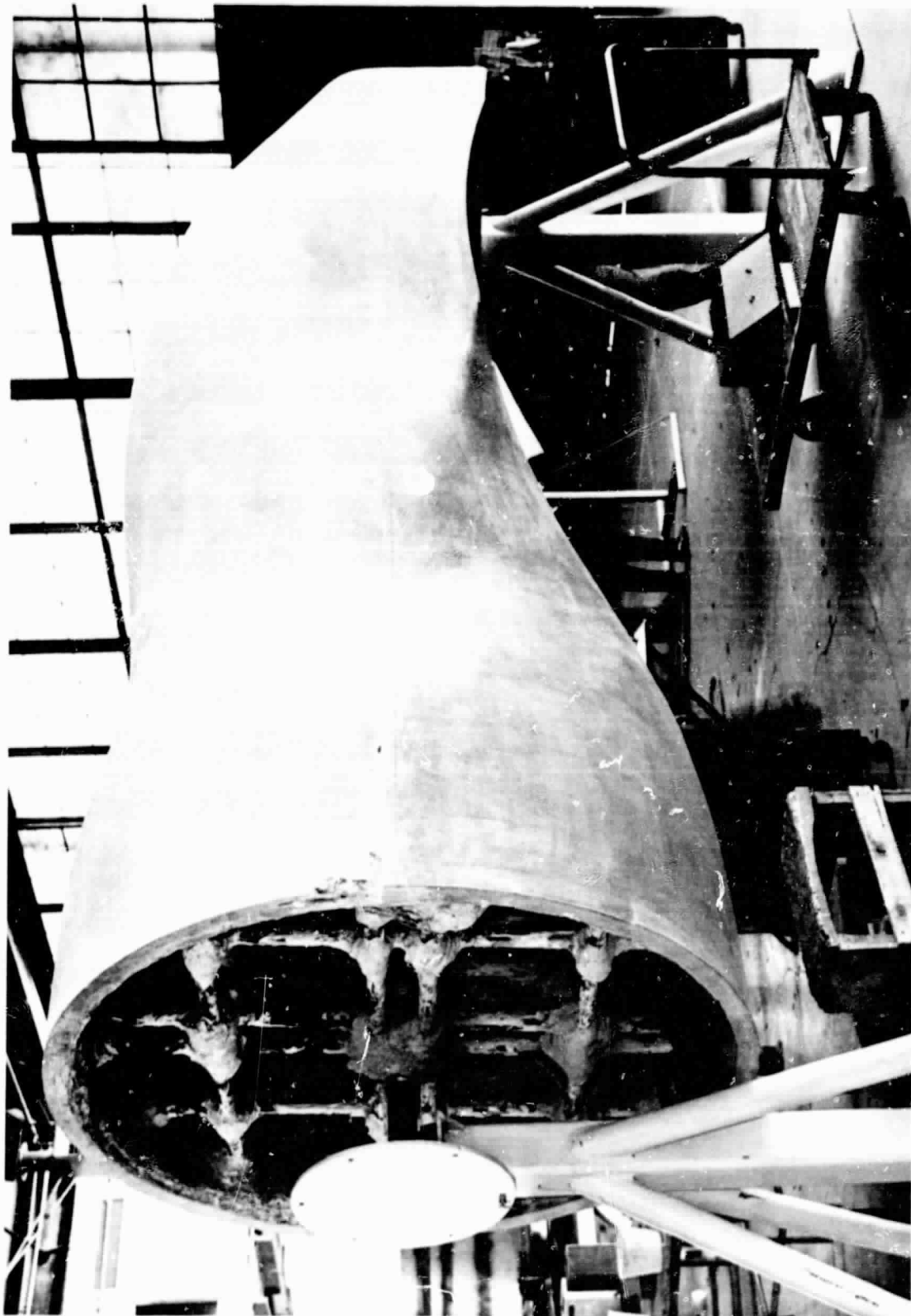


Figure 22. OTW Stretch-Forming Tool.

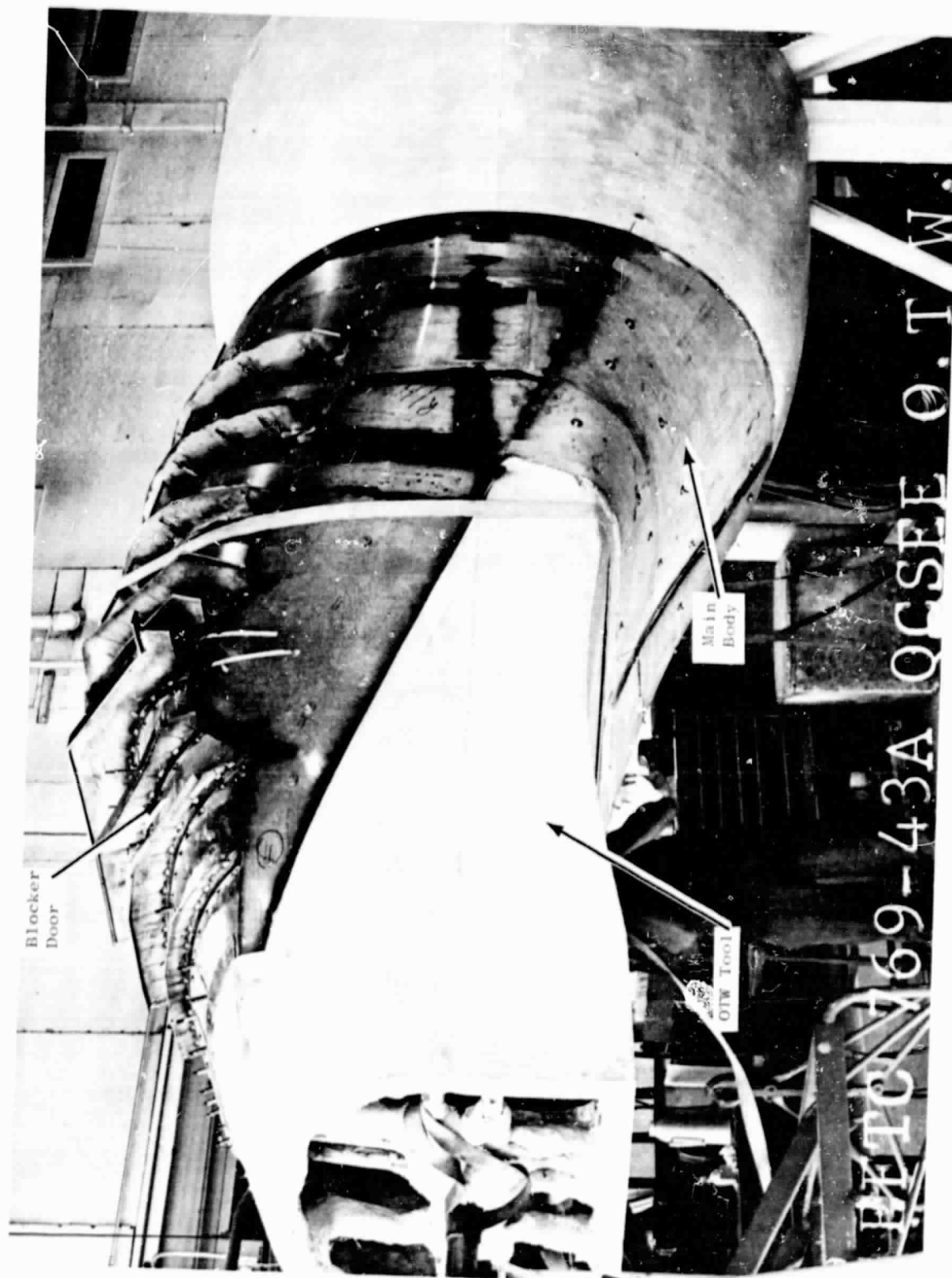


Figure 23. Main Body and Blocker Door Fabrication.

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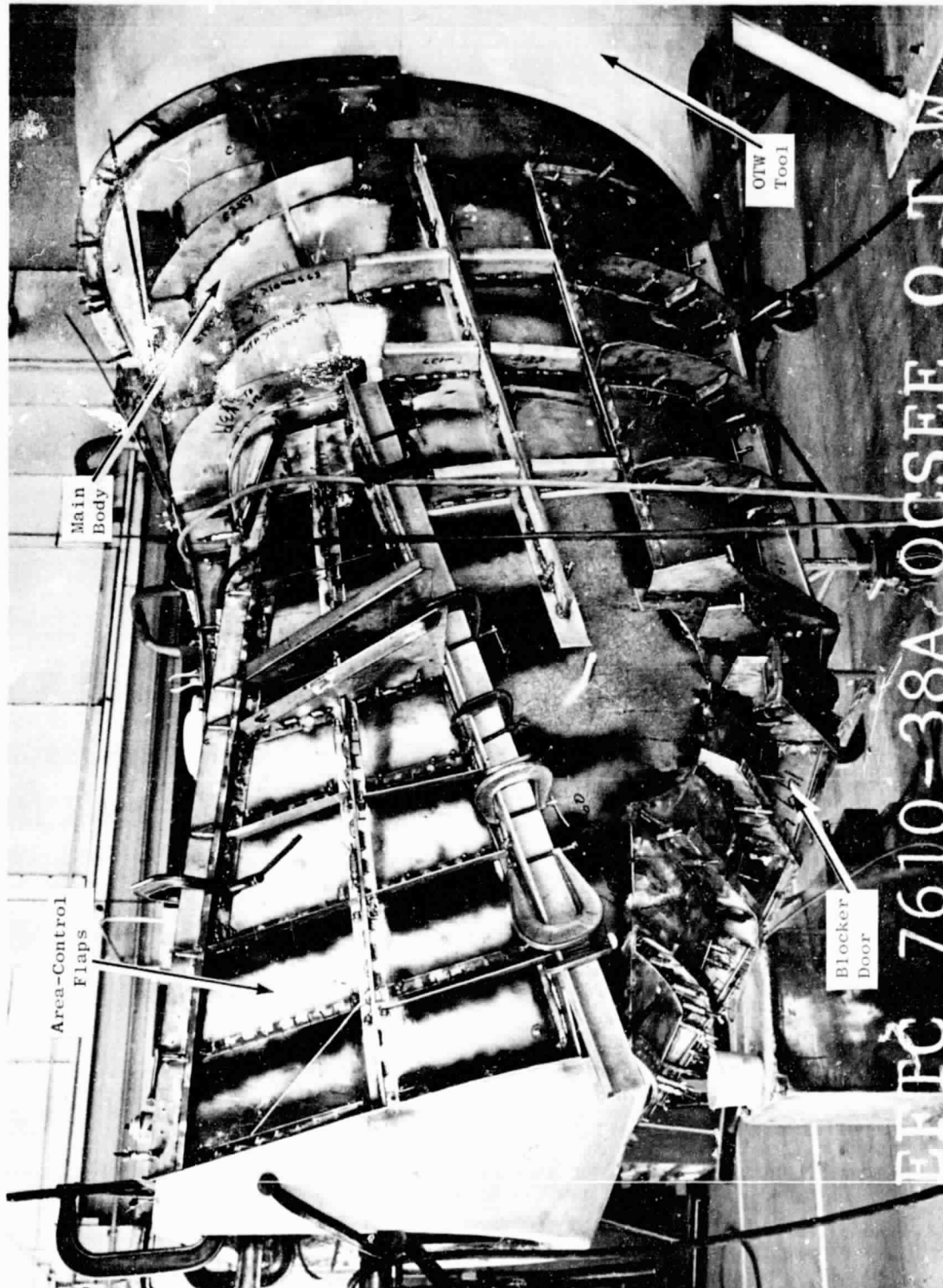


Figure 24. "D"-Shaped Nozzle Fabrication.

two forward and two aft (Figure 19). For the two forward mounting clevises, one transmits vertical, side, and aft loads and the other transmits vertical and aft loads to the facility. At the aft mount, one clevis reacts vertically and sideways, and the other reacts vertically. The final positioning and pinning of this assembly will occur at engine assembly.

a. Blocker Door

The primary feature of the thrust reverser is the blocker door (Figure 25). It is capable of rotating about the nonstructural pivot point to a "full-open" position (a cross section of the pivot point is shown in Figure 26). This is accomplished manually during engine shutdown; and, in all cases, the final configuration is firmly bolted into position.

Figure 19 delineates the "two"-position blocker door in detail. The blocker door is bolted down in the closed position. In the "full-open" position, it is bolted to the floor of the body structure for the 1.05-radians (60°) and the 1.22-radians (70°) adapter positions, to the pivotal arch (there are close-tolerance bolts provided for each open position), and to the two simulated actuator rods (they would exist for a flight version of this thrust reverser design and are adjustable for both open positions).

b. Lip Extension

The lip extension is shown in Figures 19 and 27 and is bolted to the blocker door. The intermediate flange provides the capability to demonstrate either a 0.4 or 0.6 (ratio of lip length measured axially to the flowpath height at Station 290.0) lip extension (the two lips were procured to compare reverser thrust levels with different length extensions).

c. Side Skirts and Simulated Actuators

The side skirts are shown in Figures 19 and 28. The simulated actuator is attached to the side skirt and to the forward mounting clevis for transmitting loads during the "full-open" configuration as shown in Figure 19. The simulated actuators were designed to be adjustable for the two "full-open" positions and to be removable for the closed-door position. By designing one actuator end in the side skirt instead of the blocker door, the removal of the simulated actuators and the side skirts provides a clean flowpath for the closed-door configuration.

d. Flaps/Nozzle Area Control

The flaps are shown in Figures 19 and 29. They functionally satisfy the aerodynamic requirements for a multipositional nozzle area control system. This is accomplished by a manually operated turnbuckle arrangement (Figure 30) that provides the flexibility for fine tuning the flap position during engine shutdown as required for fan mapping. For rotating the flaps, a piano hinge is used which adequately spreads out the loads with a resulting compressive condition in the turnbuckle. This design approach satisfies the functional and economical considerations for the nozzle area control problem.

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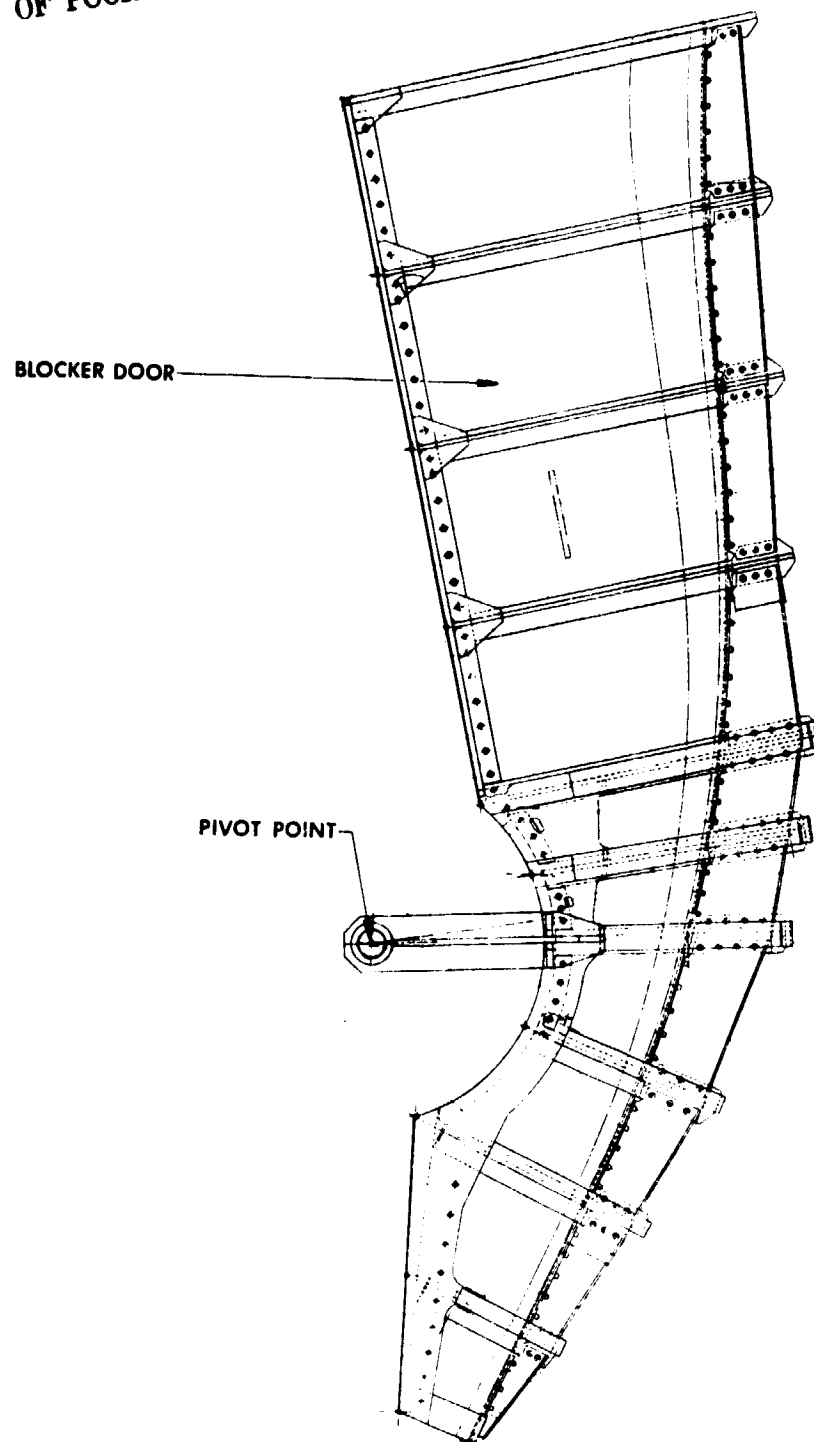


Figure 25. Blocker Door.

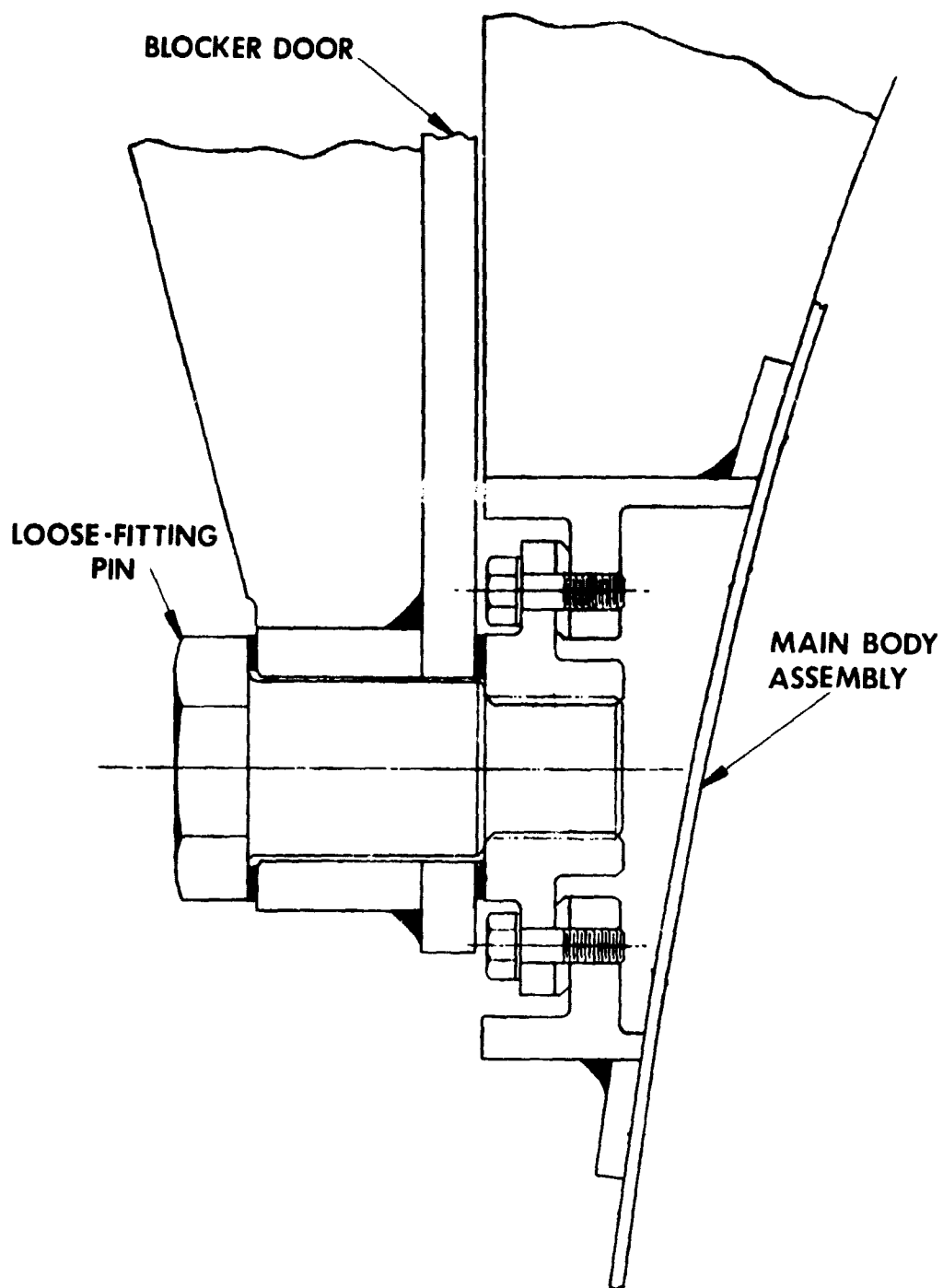


Figure 26. Pivot Point Cross Section.

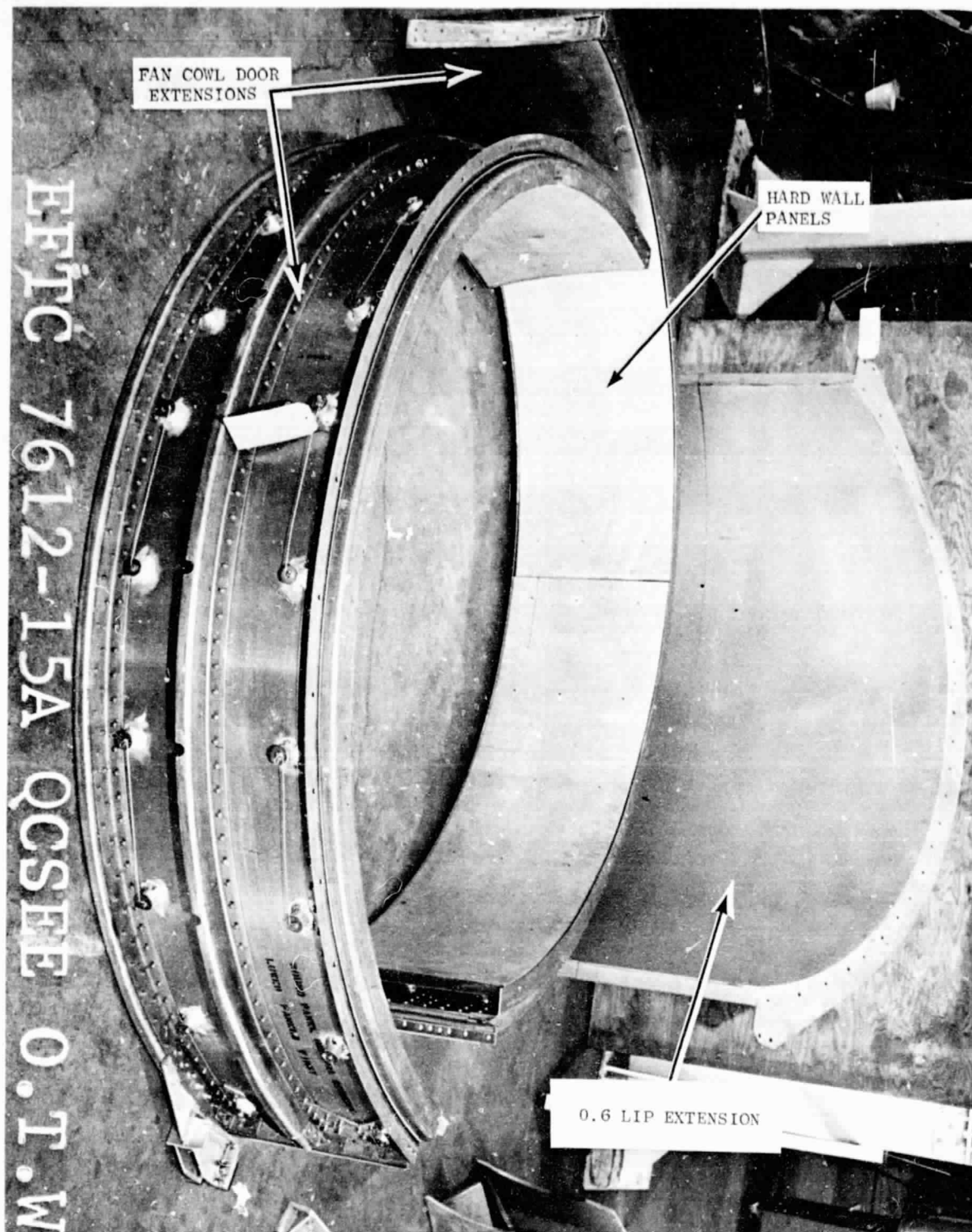


Figure 27. Lip Extension and Fan Cowl Door Extension.

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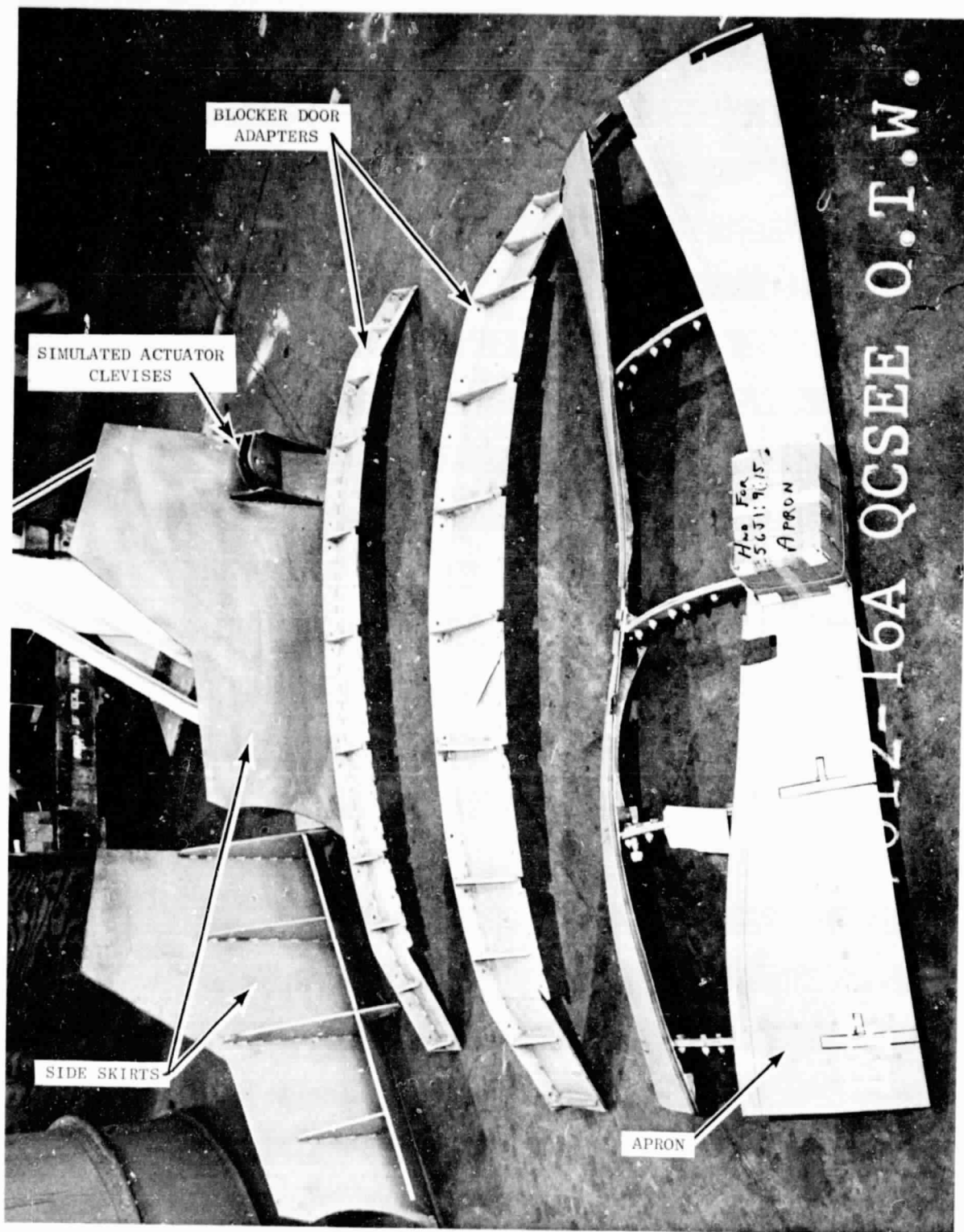


Figure 28. Side Skirts, Blocker Door Rotational Actuators, and Apron for UTW Composite-Core Cowl Doors.

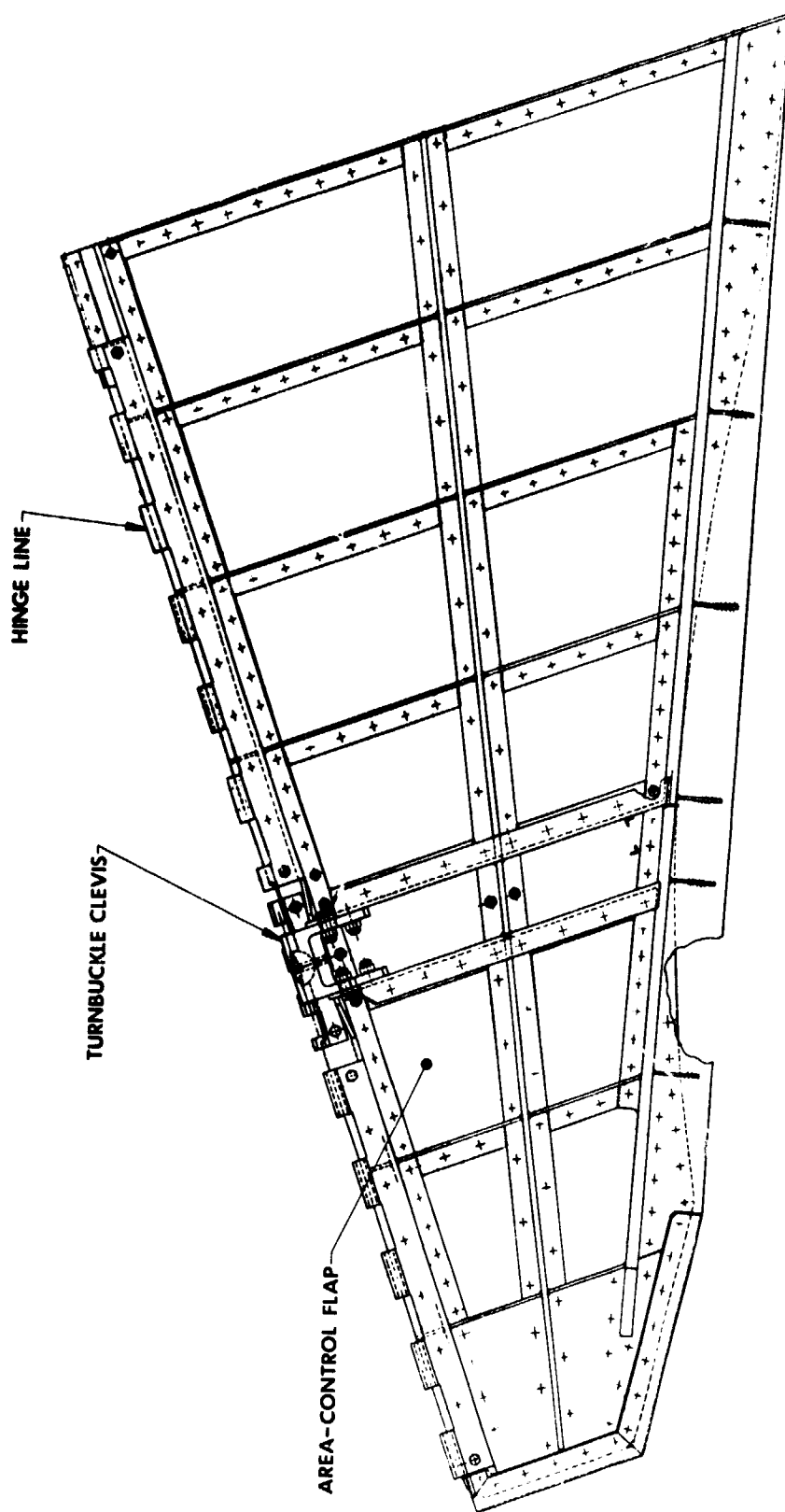


Figure 29. Area-Control Flaps.

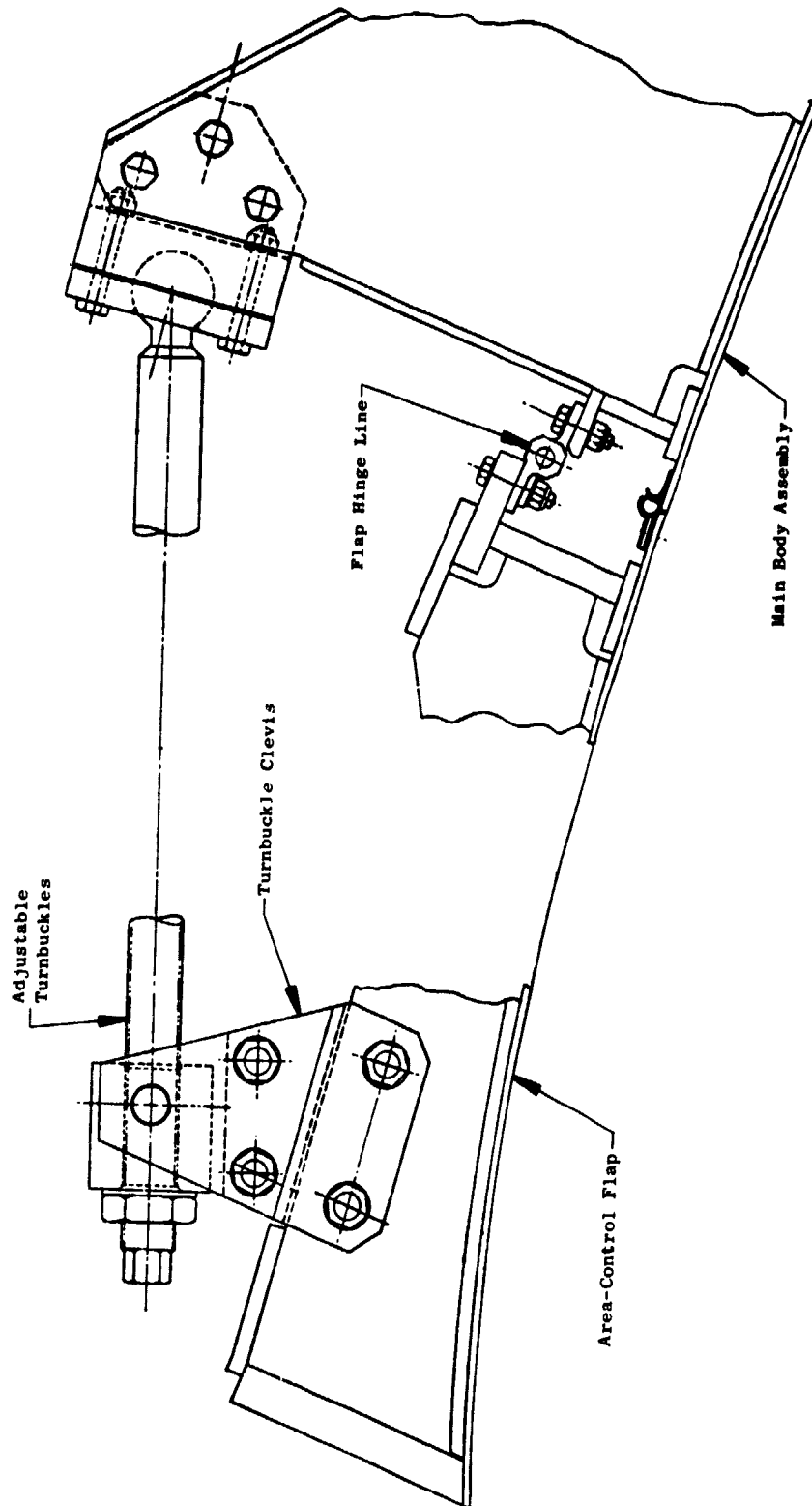


Figure 30. Turnbuckle Assembly.

## SECTION IV

### INSTRUMENTATION

A complete list of the instrumentation will not be presented here; however, it is important to note some of the design features that were implemented solely for instrumentation purposes.

In general, all provisions for aerodynamic and acoustic probes and rakes have the same design concept throughout the nacelle. The mounting bosses are firmly attached to the structural casings; and, blank-off pads are provided to fill the opening, when the instrumentation is not in use, to provide a smooth flowpath. The hard wall panels have provisions for a complete set of aerodynamic and acoustic instrumentation; however, only aerodynamic and acoustic probes can be used when the acoustic panels are installed.

The hybrid inlet utilizes four equally spaced 2.54-cm (1-in.) wide axial ribs. They form a continuous nonremovable flow line for static and dynamic pressure instrumentation. This design feature provides a nonremovable instrumentation capability for different panel configurations. The inlet also contains mounting provisions for the single strut that supports the slipring assembly.

The fan exhaust splitter has a removable section in the leading edge that provides a slot for an acoustic probe to traverse the entire flow annulus. When the probe is not in use, the slotted leading-edge piece is replaced by a full nose piece (Figure 31). Holes also are provided in the leading edge to accept traversing Cobra and dynamic-pressure probes.

The "D"-shaped nozzle assembly has no special provisions for any instrumentation. However, some instrumentation, such as wall-statics or Kulites, could be installed with a minimal effort at the test site.

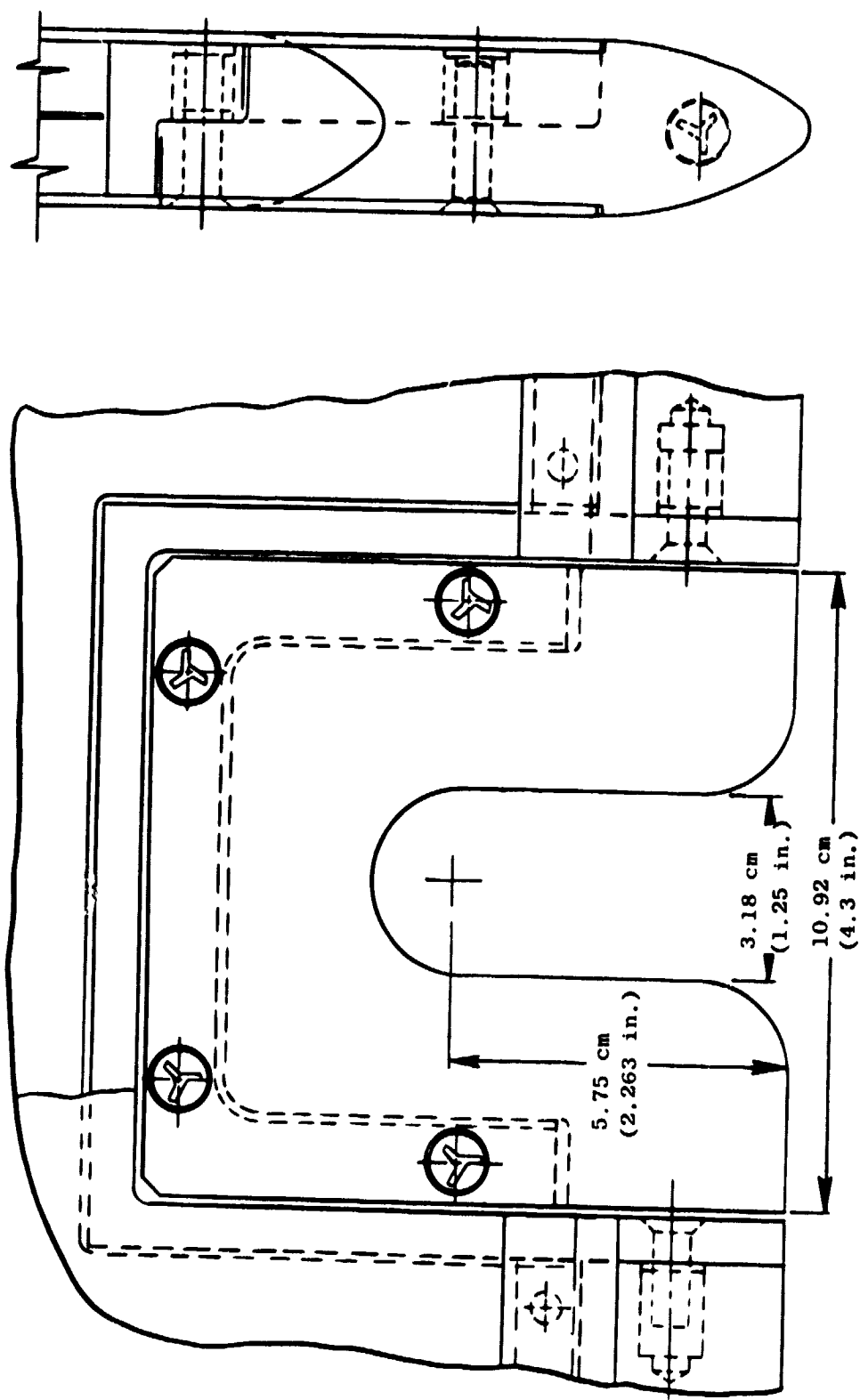


Figure 31. Splitter Instrumentation Leading Edge Provision.

## SECTION V

### NACELLE/"D"-SHAPED NOZZLE INSTALLATION

The assembly of the bellmouth, four-ring splitter, and the hybrid inlet configurations is identical and similar to all other decoupled inlet systems tested at Peebles. Relative positioning is accomplished at final assembly on the test stand by line drilling the facility mounting bars with the structural support rings provided on each inlet configuration.

The installation of the fan cowl doors, pylon, and core cowl doors (because of several close-tolerance interfaces) is a complex and difficult task. This entire assembly was fabricated to fit a close-tolerance tooling mandrel at GE-Mojave. The installation procedure is to use the assembly as an integral unit and, by fine tuning the adjustments at the facility mount interface, match the centerline of the system and the engine. Once this is accomplished, the assembly is pinned to the mounts and the installation process is complete.

All of the above components have been fitted during the UTW Build 1 phase of the program. There is no need to consider them here.

The installation of the "D"-shaped nozzle is as follows: all of the boilerplate nacelle components used in the UTW Build 1 are installed prior to the "D"-shaped nozzle installation. The fan cowl door extension is bolted to the fan doors resulting in a new fan door assembly. Figure 32 shows the OTW engine ready for the nozzle installation (note: the fan door assembly must remain open, and has been removed with the inlet from this figure for clarity). The "D"-shaped nozzle and transition section then are bolted together. Figure 33 shows this assembly prior to lifting it into position (a reinforced skid is provided as a handling crate). Final fit up of this assembly (Figure 34) is accomplished by comparing critical interfaces with the closed fan doors, the pylon closeout, and the relative positions of the nozzle mounting pins which were accurately positioned both laterally and vertically during fabrication. After all fits are found to be acceptable, the nozzle support structure is pinned to the overhead facility structure.

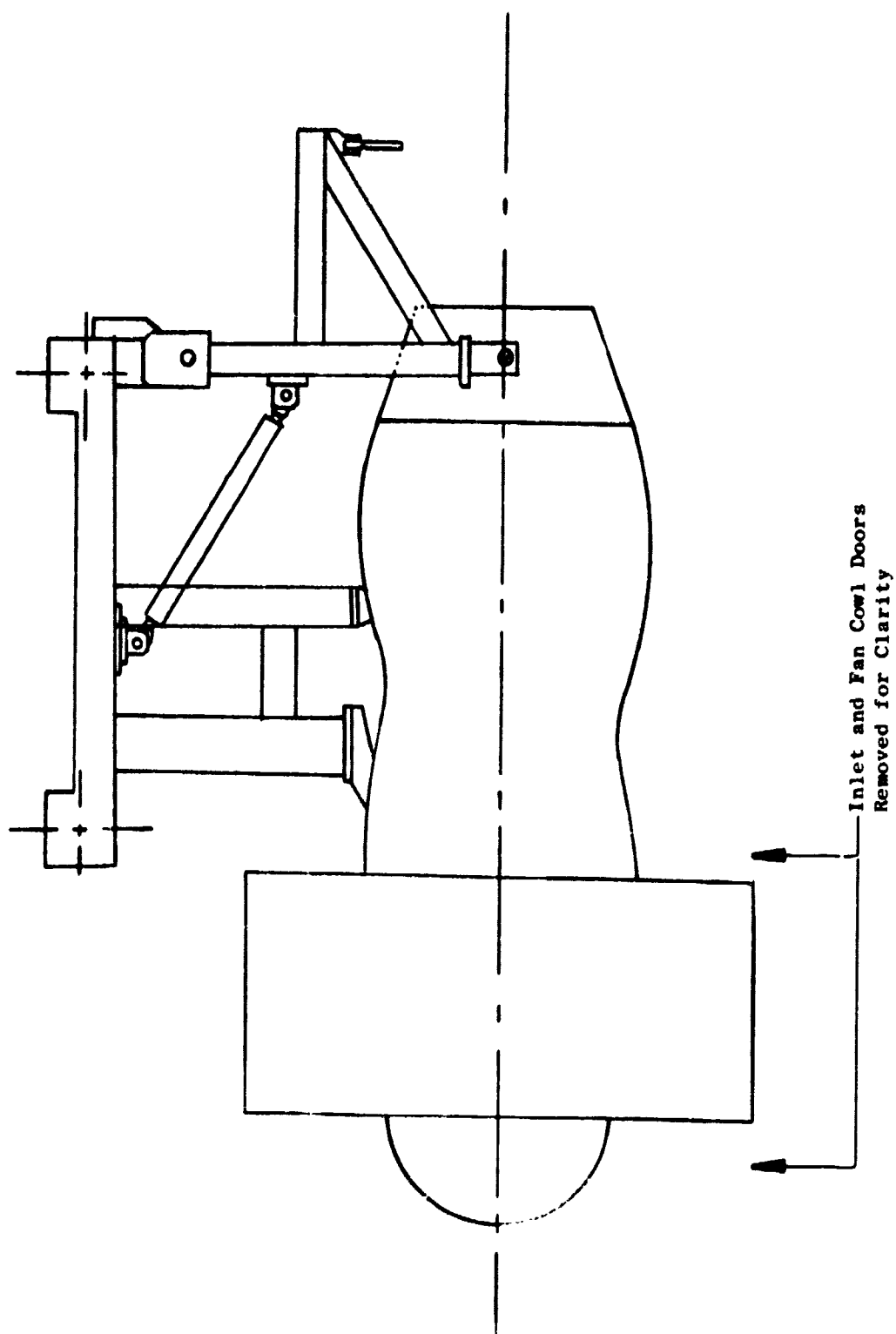


Figure 32. OTW Engine Prior to "D"-Shaped Nozzle Installation.

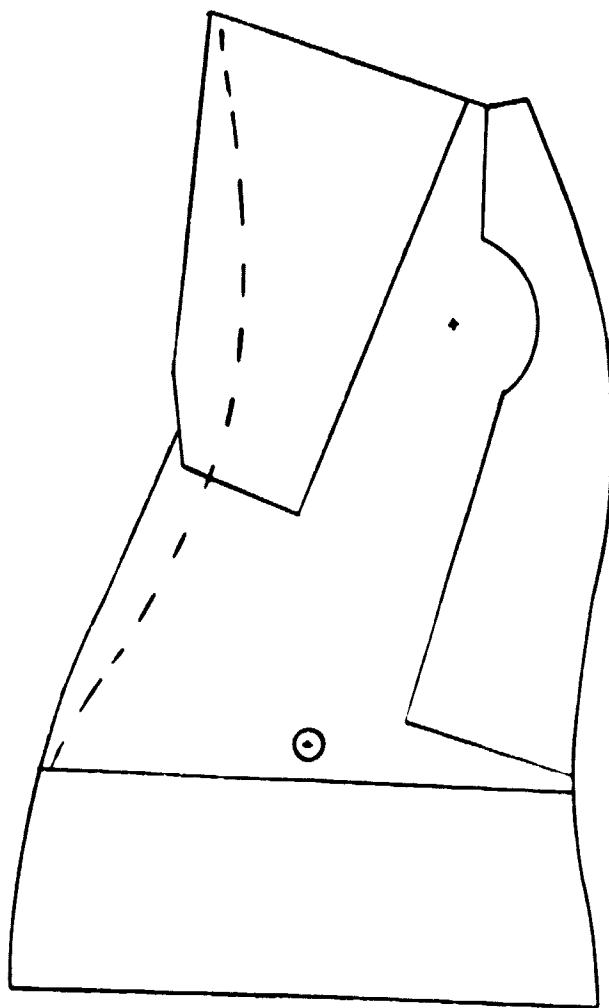


Figure 33. "D"-Shaped Nozzle Ready for Installation.

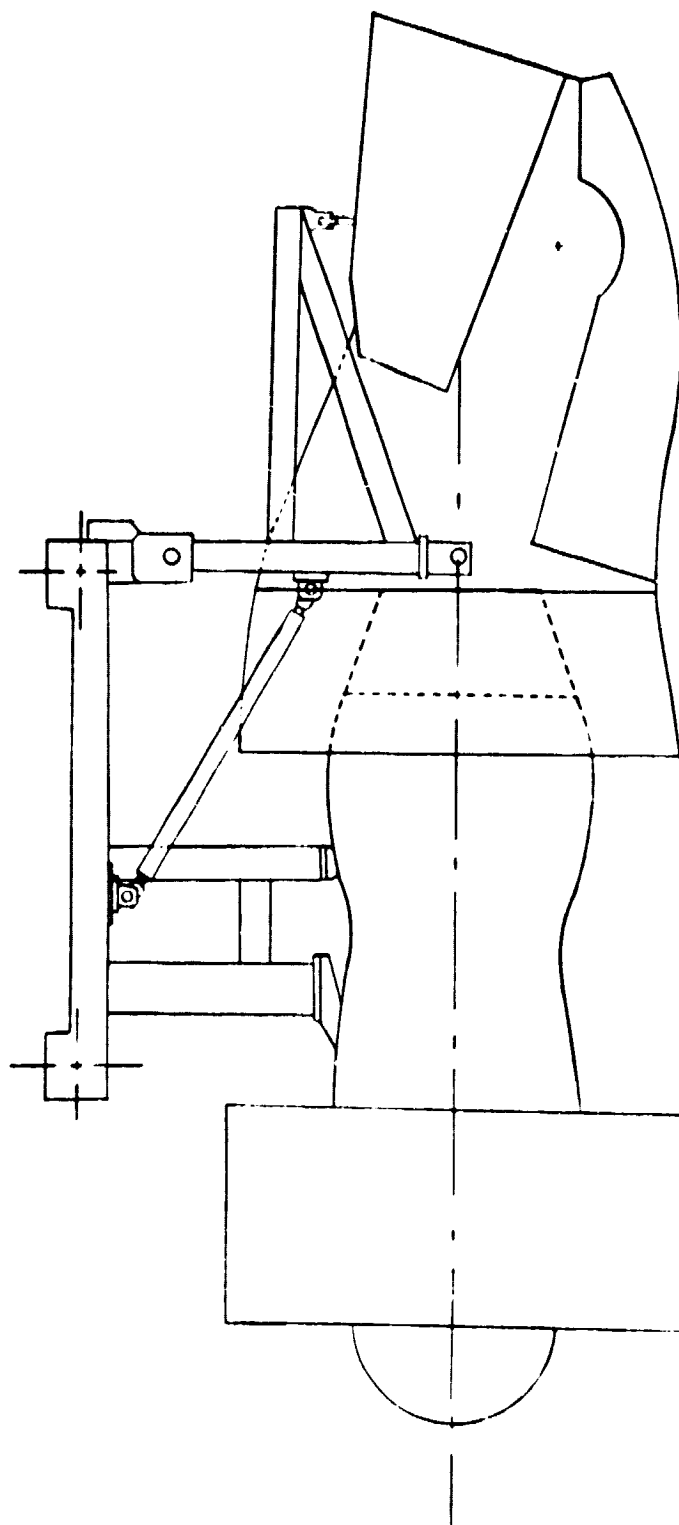


Figure 34. Final Installation.

## SECTION VI

### ANALYSIS

The following is a summary of the strength, stiffness, and continuity of the "D"-shaped nozzle assembly of the OTW boilerplate nacelle. Since the basic philosophy was to design a high-strength, fatigue-resistant structure, this component will be shown to be considerably overstrength. This concept is standard practice for test hardware of this type.

#### A. SPLITTER/STRUT SYSTEM

Steady-state design of the UTW splitter struts for the OTW configuration proved that the stresses did not intersect the Goodman-limit curve below an  $A=1$  line [ $\sigma_{ss} = 68.95 \text{ N/cm}^2$  (100 psi)]. This criterion assured that the allowable vibratory stress will always be greater than the steady-state stress, a condition which experience dictates to be desirable. Stress and vibratory analyses were performed using the GE "Twisted Blade" program.

Aeromechanically, it is desirable that the cross section (stiffness parameters) of the airfoils be designed such that the first flexural and first torsional modes should not be excited by blade passing frequencies in the 60-110% speed range. Economies in the program, however, dictated that the UTW and OTW programs share a common strut design. A close evaluation of Figure 35 shows that the blade passing excitation frequency crosses the first flexural and torsional response frequencies within the 60-110% bandwidth. However, the design is such that the strut end fixities are built-in to simulate a fixed-fixed condition which definitely places the level of the first flexural and torsional response frequencies well above the unstable one- and two-per-rev (integral multiple of rotor speed) excitation range. Since the blade passing excitation energy will be significantly damped due to the effect of the frame OGV's, the low pressure ratio of the fan, and the overall distance between the fan blades and the splitter leading edge, it has been concluded that no problem is anticipated with this design.

An area of major concern on test engines of this type is that of system critical frequency. Normal design practice dictates the avoidance of all rotor criticals up to at least 110% physical speed. Resonances associated with stationary components, such as the splitter strut system, are mechanically tuned to fall out of the critical range between 60-110% physical speed where high-energy excitation could be encountered for an extended time period. The analytical model used the strut stiffness parameters to achieve acceptable system vibration characteristics. The splitter was assumed to be a rigid body due to its integral sandwich construction. (Note: the basic difference between the UTW and OTW splitter configurations is in the removable trailing edge which affects the mass parameter in the system vibration equations.)

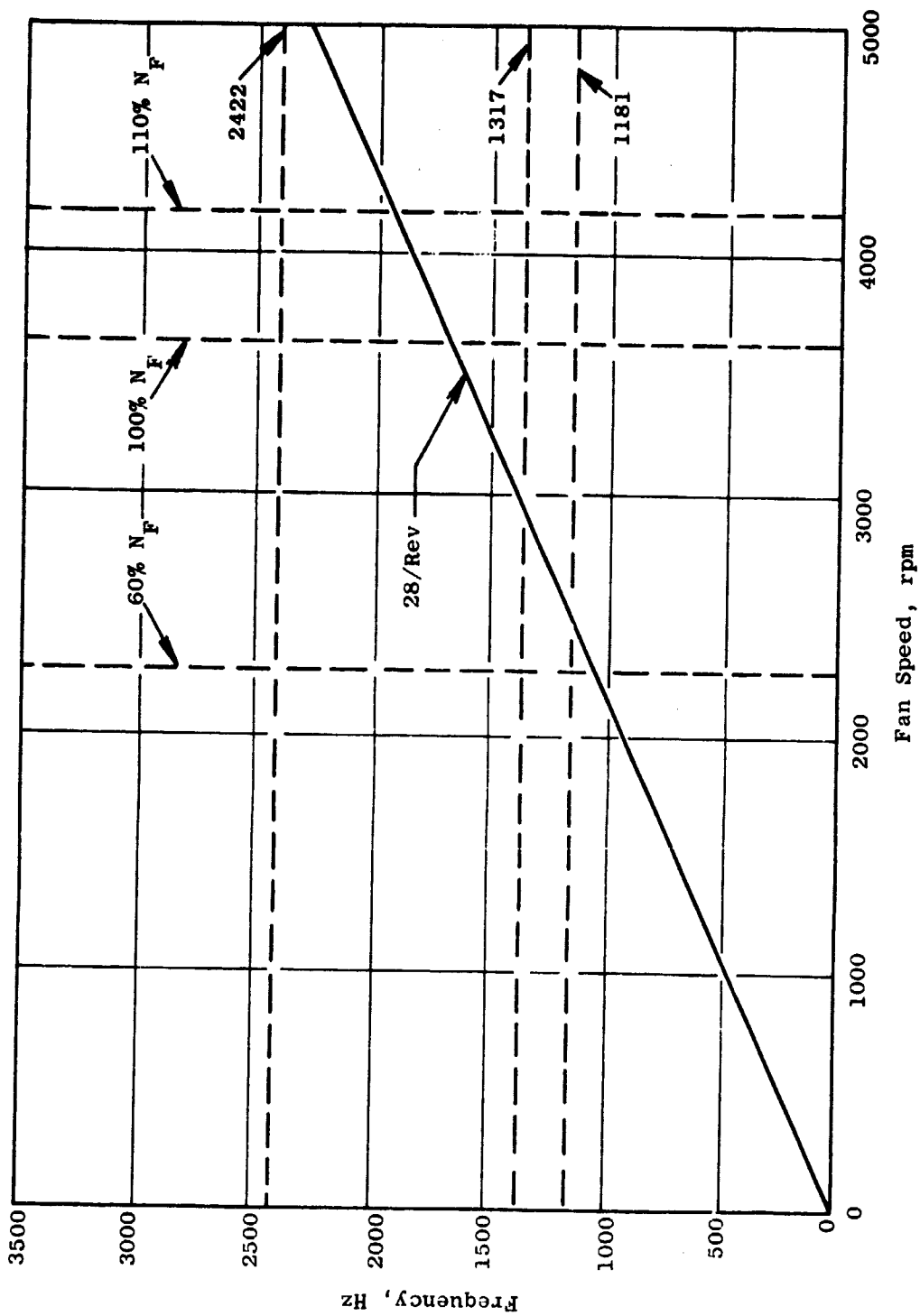


Figure 35. OTW Splitter Struts, Critical Speed Diagram.

A system mode is one in which vibratory coupling occurs between the struts and the splitter. The interplay between these two components resulted in the selection of stainless steel struts and an aluminum splitter. The advantage of the final configuration is the increased frequency level of the lowest-energy system modes. These frequency levels provide the ability to avoid rotor blade-passing resonance in the one- and two-per-rev spectrum, while maintaining a reasonable margin below the higher excitation energies that can occur at or above the 60% speed ranges (see Figure 36).

#### B. "D"-SHAPED NOZZLE ASSEMBLY

The loading conditions used to establish the design features of this assembly are based on a calculated aerodynamic estimate. The 155,680-N (35,000-lb) load in the aft direction was conservatively established by assuming that the load resulted from turning 100% of the flow 3.14 radians (180°). The 48,928-N (11,000-lb) vertical load is a conservative extrapolation of existing aerodynamic data from a scale model D-nozzle test program at NASA-Langley (Ref. Report Nos. GE 76AEG407 or NASA CR2792 - Analysis and Documentation of QCSEE OTW Exhaust System Development). For a test program of this type, it is absolutely essential that the analysis prove the integrity of the design for all conditions; therefore, the above loads are multiplied by a factor of 1.5 before they are applied to the structure. The resulting loads are applied to the structure and reacted at the facility mounting points:

$$1.5 \times P_{\text{aft}} = 692,464 \text{ N (52,500 lb)}$$

$$1.5 \times P_{\text{vert}} = 217,632 \text{ N (16,500 lb)}$$

The loads applied to the nozzle area control flaps are calculated from the aerodynamic pressure distribution in the forward mode. The results are:

$$P_{\text{flap}} = 5328 \text{ N (1200 lb)}$$

$$\text{or: } 1.5 \times P_{\text{flap}} = 7992 \text{ N (1800 lb)}$$

The calculated weight of the structure was found to be 14,825 N (3333 lb).

Define:

$$\text{Factor of safety (F.S.)} = \frac{\text{Allowable Stress}}{\text{Actual Stress}}$$

#### 1. Blocker Door/Side Skirt

The loading conditions used to establish the interface design of the blocker door and its mating components were found as follows: the resultant load of the vertical and aft components was distributed as an equivalent pressure on the blocker door.

$$\text{Applied Load: } 1.5 \times R = 244,782 \text{ N (55,032 lb)}$$

$$\text{or Equivalent Pressure: } p = 7.1 \text{ N/cm}^2 \text{ (10.3 psi)}$$

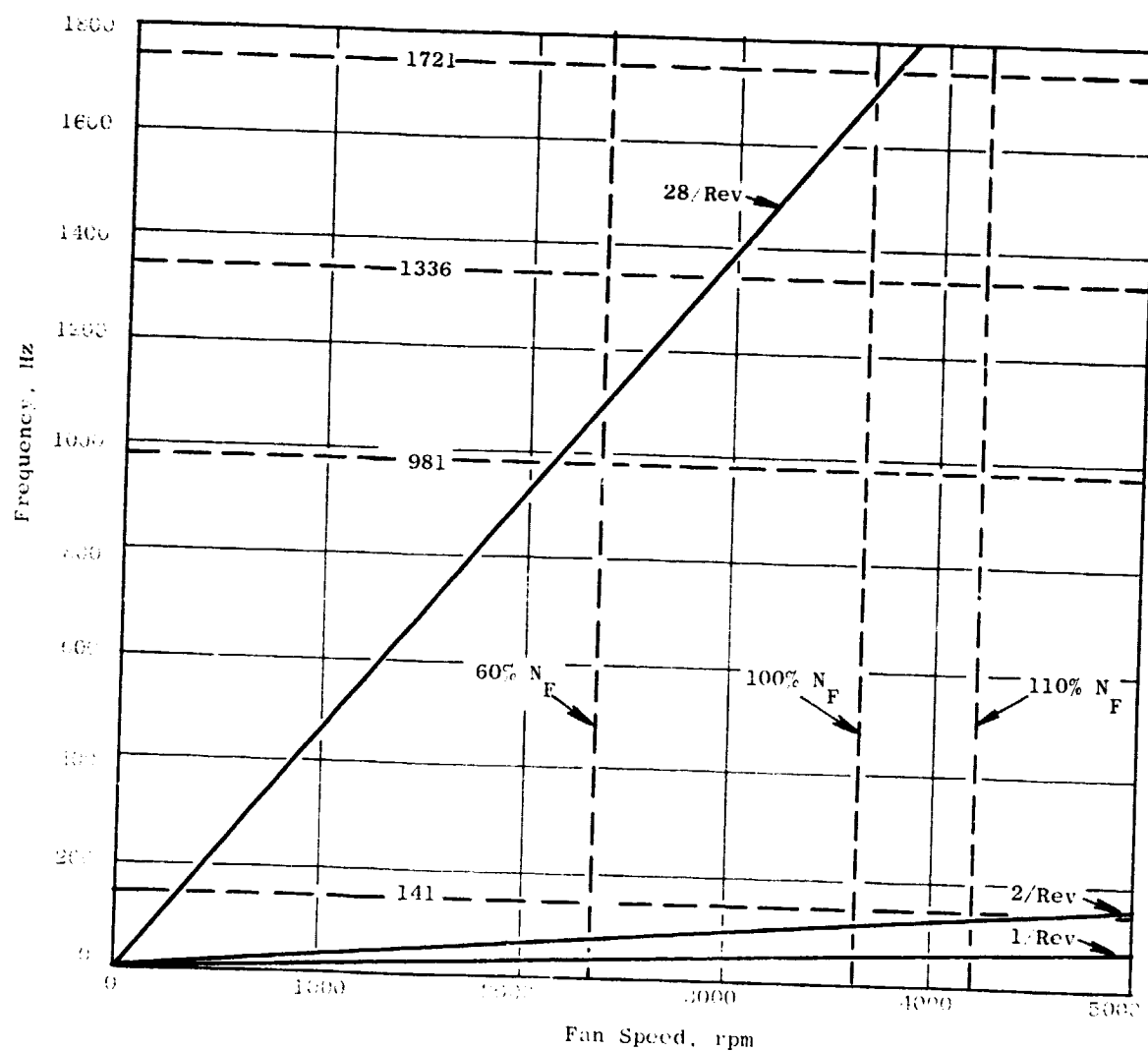


Figure 36. OTW Splitter with Steel Struts, Critical Speed Diagram.

The blocker door in the open position is bolted to the floor of the main body, bolted to the pivot point structure (but not through the pivot point), and attached to the forward mount structure through the side skirts/simulated actuator rods. The analysis of the side skirt was performed by cutting the reaction at the floor of the main body (see Figure 37).

a. Side Skirt Clevis - See Figure 38

The bolt (body-bound) used to attach the simulated actuator to the side skirt has a 2.22-cm (0.875-in.) diameter.

$$\text{Shear Stress} = 11,707 \text{ N/cm}^2 \text{ (16,979 psi)}$$

$$\text{F.S.} = 1.32$$

$$\text{Bending Stress} = 36,751 \text{ N/cm}^2 \text{ (53,301 psi)}$$

$$\text{F.S.} = 2.35$$

b. Side Skirt Stiffener at Clevis - See Figure 39

Assuming that the entire load is reacted by the local stiffener at the clevis, then the two 0.953-cm (0.375-in.) bolts must react the load in shear.

$$\text{Shear Stress} = 28,380 \text{ N/cm}^2 \text{ (41,160 psi)}$$

$$\text{F.S.} = 1.82$$

Or, the entire load must be reacted by a single bolt in tension.

$$\text{Tensile Stress} = 13,797 \text{ N/cm}^2 \text{ (20,010 psi)}$$

$$\text{F.S.} = 6.25$$

c. Side Skirt Flange - See Figure 40

Assume that the remainder of the bolts in this flange must react 50 percent of the equivalent pressure found on the blocker door.

$$\text{Flange Bending Stress} = 23,806 \text{ N/cm}^2 \text{ (34,526 psi)}$$

$$\text{F.S.} = 1.26$$

That flange bending stress is reacted by the bolts in the flange.

$$\text{Bolt Tensile Stress} = 24,620 \text{ N/cm}^2 \text{ (35,895 psi)}$$

$$\text{F.S.} = 3.48$$

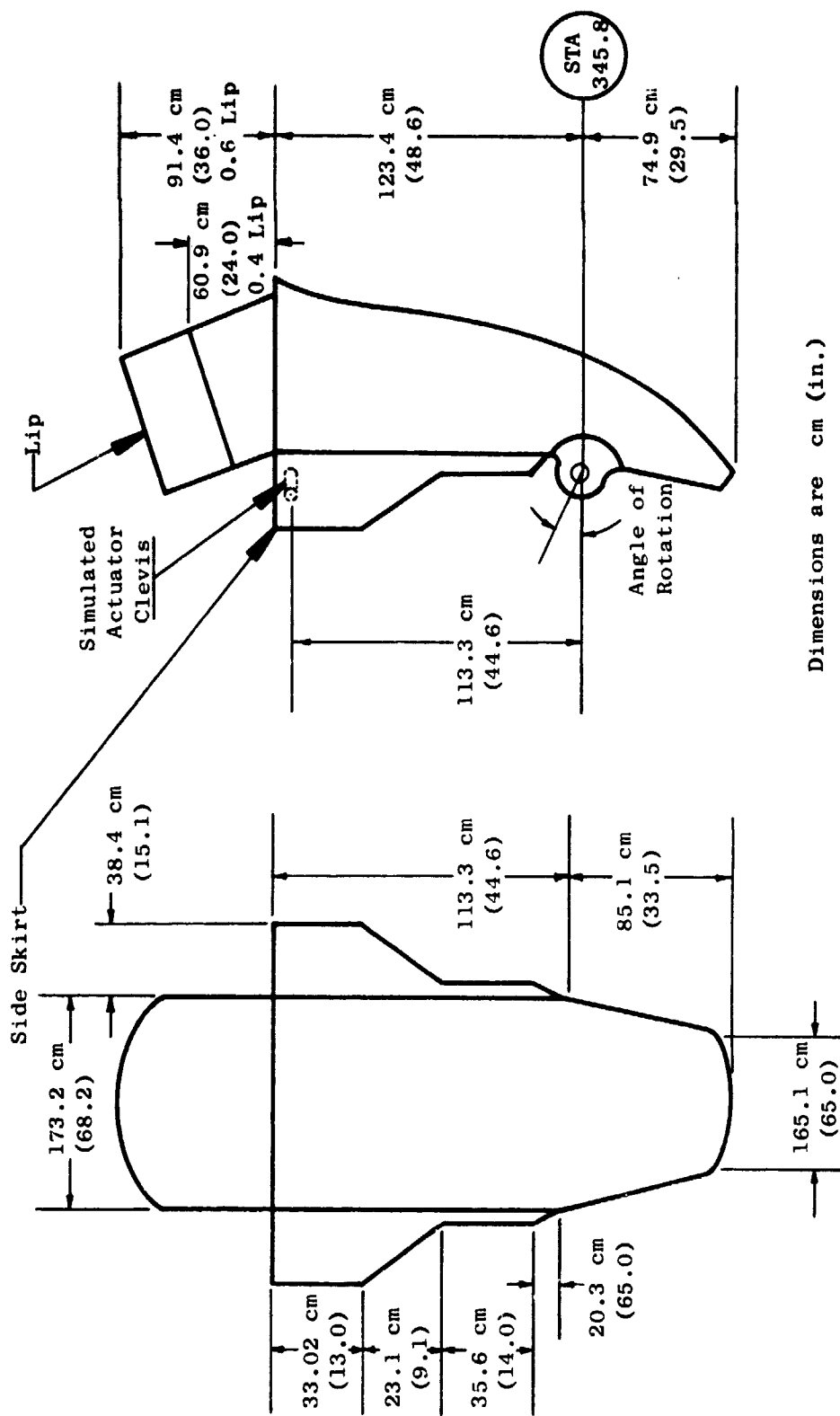
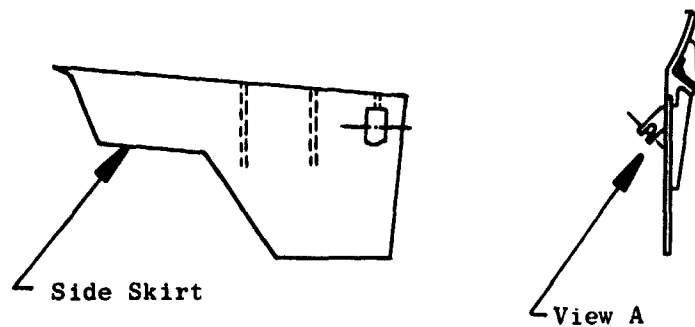


Figure 37. Blocker Door Assembly (Schematic).



Dimensions are cm (inches)

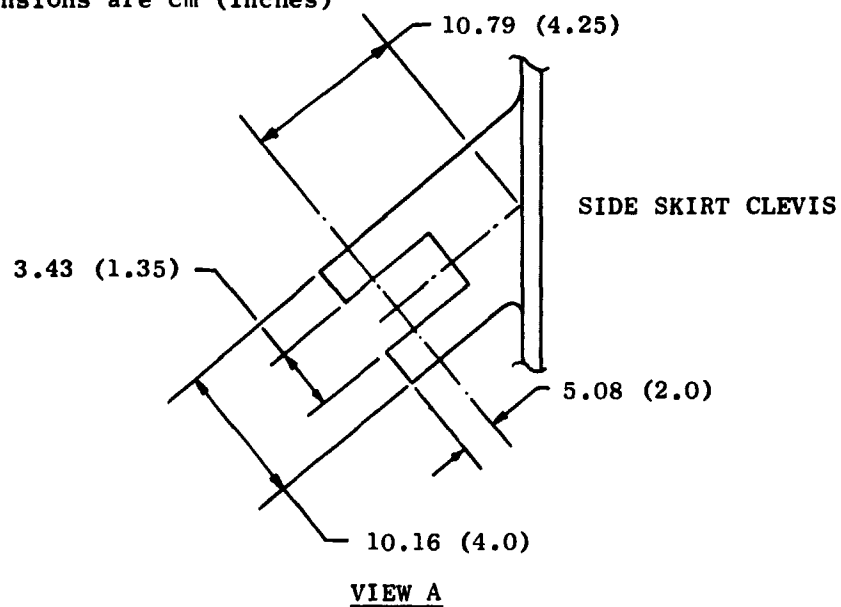


Figure 38. Side Skirt and Clevis Schematic.

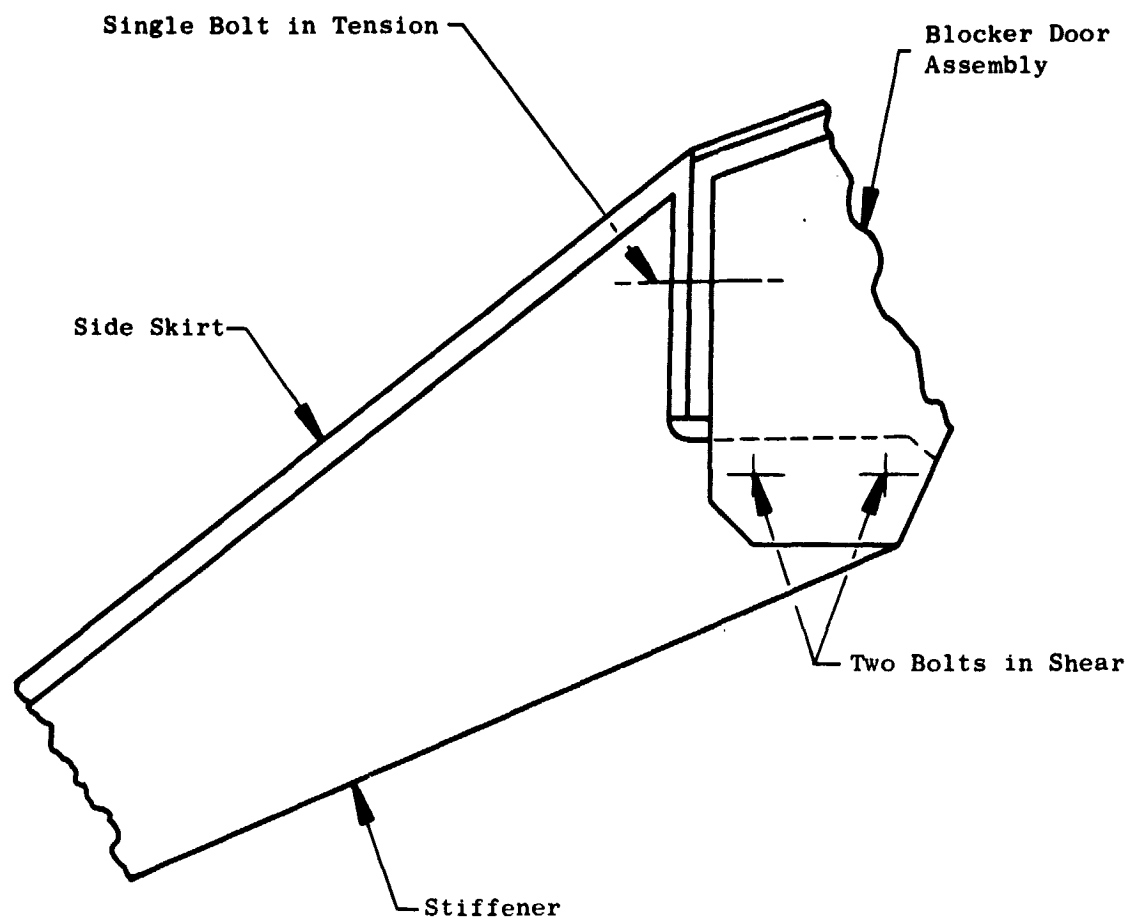


Figure 39. Side Skirt Stiffener at Clevis.

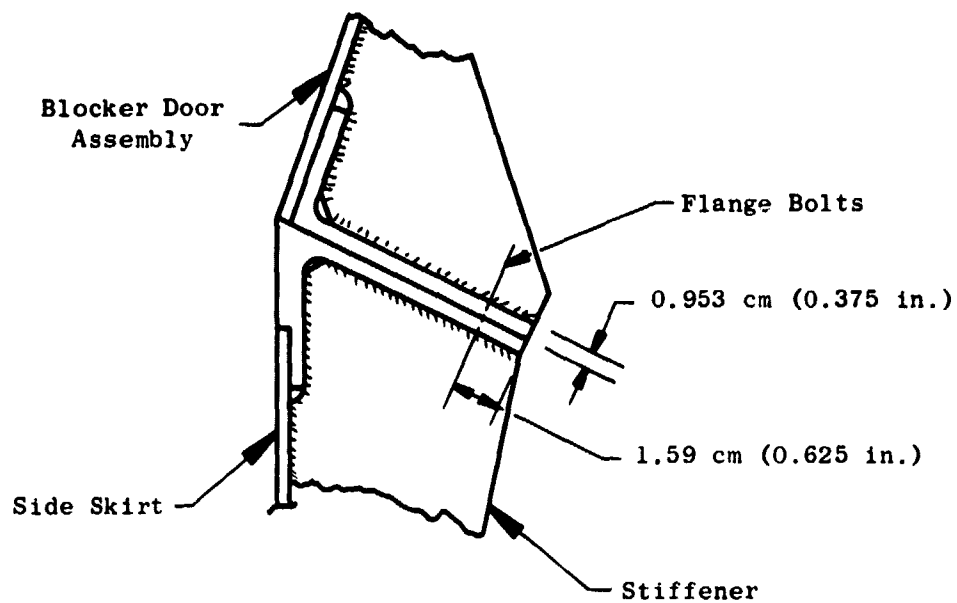


Figure 40. Side Skirt Flange.

## 2. Blocker Drop/Lip Extension Flange

The flange and bolts of the 0.6 lip extension must react the moment resulting from the following: assuming 50% of the equivalent pressure found on the blocker door creates a force (the new pressure times the projected area) acting at the midpoint of the projected area resulting in a moment at the lip extension flange interface. The moment, in turn, becomes an over-turning moment that is reacted as tensile load in the flange bolts. The following results are for the flange and the highest loaded bolt in the system.

Flange Bending Stress =  $26,433 \text{ N/cm}^2$  (38,336 psi)

F.S. = 1.7

Flange Shear Stress =  $305 \text{ N/cm}^2$  (442 psi)

F.S. = 50.6

Flange Tensile Stress =  $828 \text{ N/cm}^2$  (120 psi)

F.S. = 36.2

Bolt Shear Stress =  $9108 \text{ N/cm}^2$  (13,210 psi)

F.S. = 5.7

Bolt Tensile Stress =  $3354 \text{ N/cm}^2$  (4865 psi)

F.S. = 18.0

## 3. Blocker Door - Closed Position

The maximum delta pressure from Station 290 to Station 374.4 times the 1.5 factor is less than  $2.1 \text{ N/cm}^2$  (3 psi). Considering that the edges of the door are bolted down all around, this analysis is not critical when compared to the open position.

## 4. Flaps/Nozzle Area Control - See Figure 41

The ultimate flap load was obtained from aerodynamic pressure distribution data for closed flaps at the takeoff condition. The total load is 8006 N (1800 lb). Assuming that the center of area and the center of pressure are synonymous, the maximum hinge moment becomes 235,379 cm-N (20,830 in-lb). These loads will be used to show the ruggedness of this component. Even though the flap is bolted to the base (floor) of the main body of the nozzle assembly in the closed position, the analysis was performed by neglecting this redundancy.



a. Jackscrew - See Figure 42

The primary consideration for this item is critical buckling:

$$P = 19,375 \text{ N (4356 lb)}$$

$$P_{\text{CRIT}} = 908281 \text{ N (204,200 lb)}$$

$$\text{F.S.} = 46.8$$

b. Hinge Flanges - See Figure 43

A shear-moment diagram resulted in the following flange stresses:

$$\text{Bending Stress} = 21,848 \text{ N/cm}^2 (31,687 \text{ psi})$$

$$\text{F.S.} = 3.2$$

$$\text{Compressive Stress} = 3008 \text{ N/cm}^2 (4,363 \text{ psi})$$

$$\text{F.S.} = 13.8$$

$$\text{Shear Stress} = 3623 \text{ N/cm}^2 (5,255 \text{ psi})$$

$$\text{F.S.} = 10.2$$

c. Bolts Attaching the Hinge

$$\text{Tensile Stress} = 19,496 \text{ N/cm}^2 (28,276 \text{ psi})$$

$$\text{F.S.} = 3.0$$

$$\text{Shear Stress} = 17,782 \text{ N/cm}^2 (25,790 \text{ psi})$$

$$\text{F.S.} = 2.9$$

d. Hinge Pin Shear Stress

$$\text{Shear Stress} = 16,033 \text{ N/cm}^2 (23,254 \text{ psi})$$

$$\text{F.S.} = 2.3$$

5. Pivot Area/Main Body of Nozzle Assembly - See Figure 44

The actual pivot point is a nonstructural point that is used as a point of reference for blocker door rotations. The loads that are transmitted from the blocker door to the main body assembly are carried through two bolts per side that are match-drilled for the closed and two rotated positions.

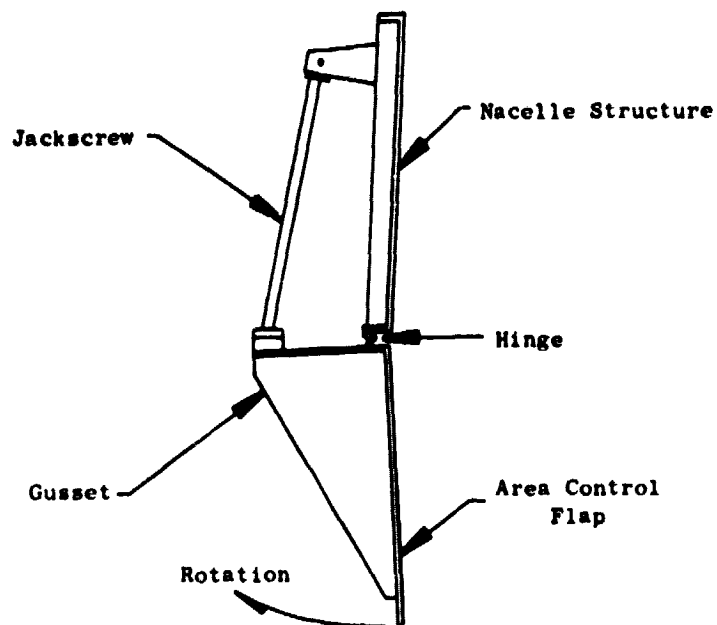


Figure 42. Jackscrew Schematic.

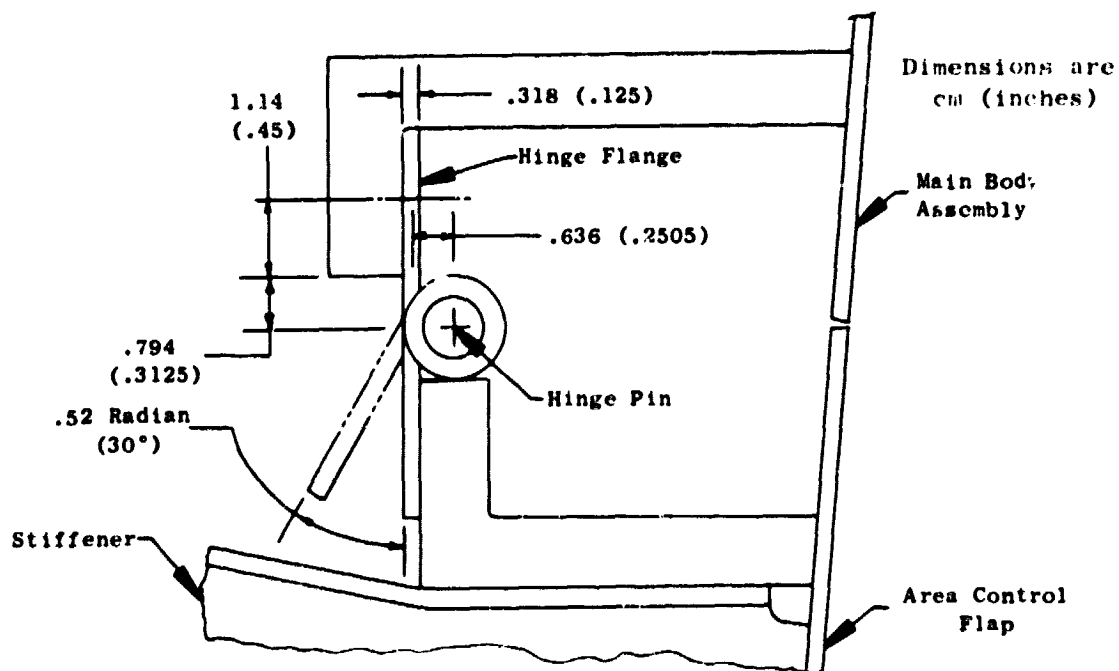


Figure 43. Hinge Schematic.

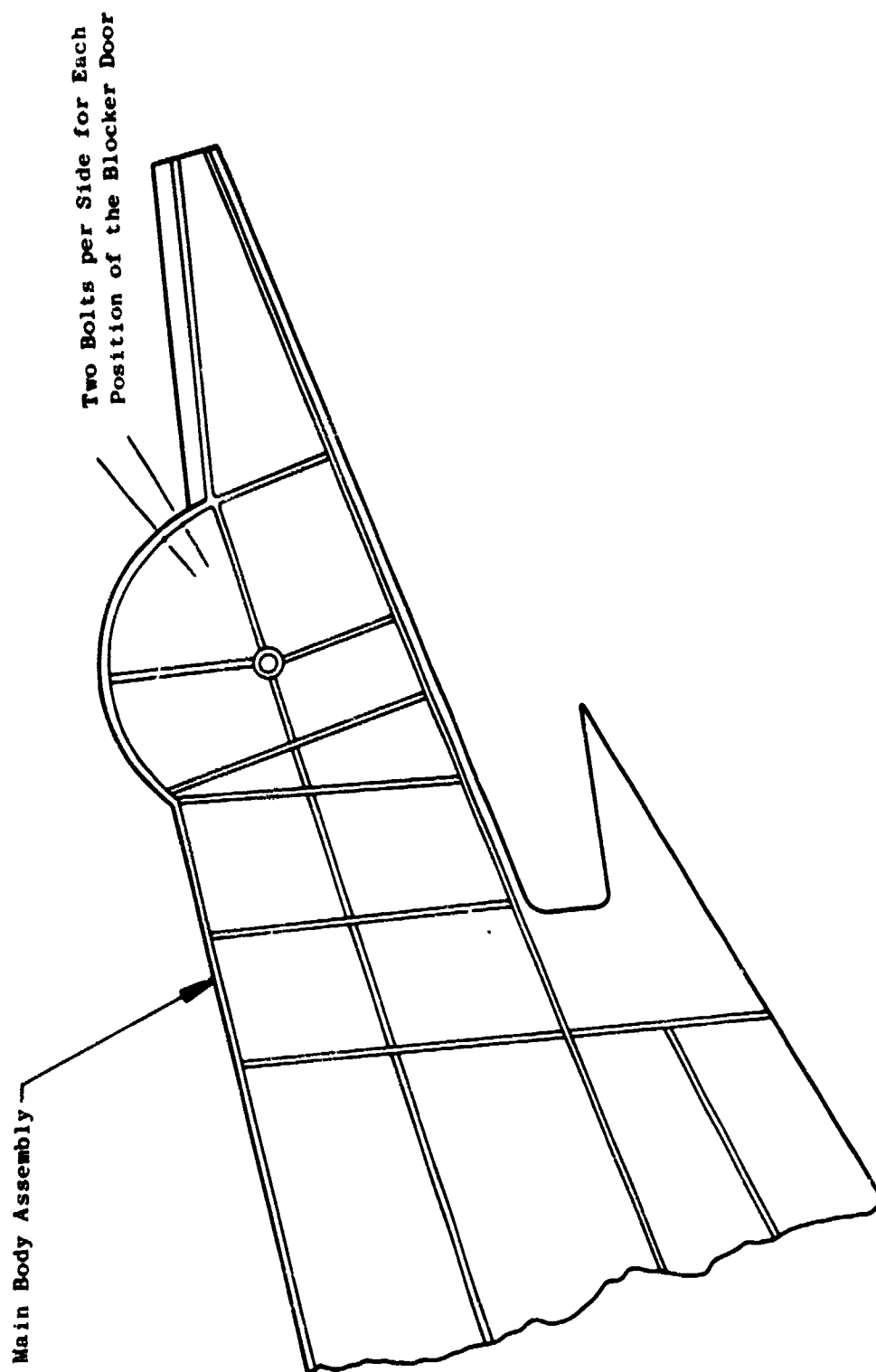


Figure 44. Main Body of Nozzle Assembly.

Tensile Stress =  $23,189 \text{ N/cm}^2$  (33,631 psi)

F.S. = 3.7

Shear Stress =  $3865 \text{ N/cm}^2$  (5605 psi)

F.S. = 13.3

#### 6. Mount Fittings

The mount fittings must react the loads transmitted to the facility (times the 1.5 factor) plus the loads from the blocker door (from the simulated actuator).

$P_{\text{aft}} = 233,519 \text{ N}$  (52,500 lb)

$P_{\text{vert}} = 73,392 \text{ N}$  (16,500 lb)

$P_{\text{actuator}} = 30,611 \text{ N}$  (6882 lb)

##### a. Forward Mount - See Figure 45

The simulated actuator:

Pin Shear Stress =  $8,753 \text{ N/cm}^2$  (12,694 psi)

F.S. = 4.6

Pin Bending Stress =  $67,202 \text{ N/cm}^2$  (97,466 psi)

F.S. = 1.3

The fitting is bolted to the main body assembly through forward and aft flanges. In both cases, conservatively react the loads by the two outermost bolts.

Forward Flange:

Flange Bending Stress =  $54,982 \text{ N/cm}^2$  (79,742 psi)

F.S. = 1.8

Bolt Shear Stress =  $23,486 \text{ N/cm}^2$  (34,062 psi)

F.S. = 2.2

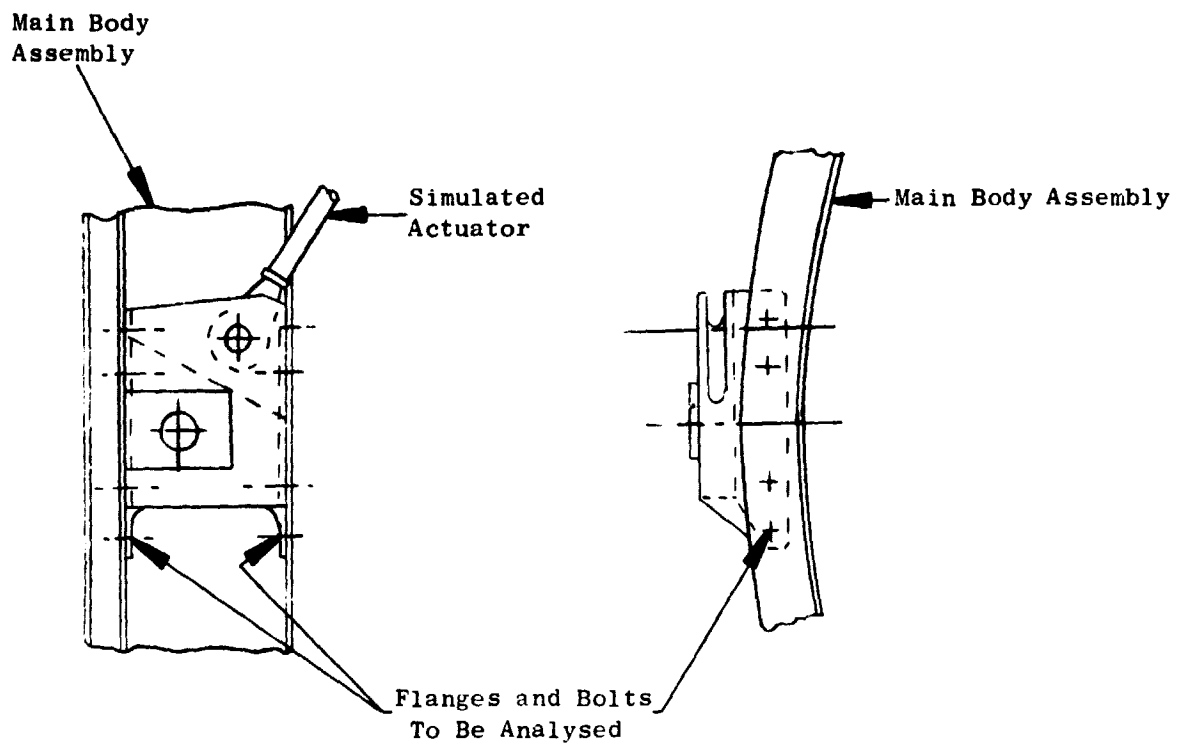


Figure 45. Forward Mount.

**Aft Flange:**

Flange Bending Stress =  $66,579 \text{ N/cm}^2$  (96,561 psi)

F.S. = 1.5

Bolt Shear Stress =  $28,936 \text{ N/cm}^2$  (41,966 psi)

F.S. = 1.8

**b. Aft Mount - See Figure 46**

(Note: only one fitting has side-load capability.)

For the bolts that fasten the fitting to the structure:

Bolt Shear Stress =  $9932 \text{ N/cm}^2$  (14,405 psi)

F.S. = 5.2

The above sampling of stress calculation clearly shows the ruggedness of this assembly. This presentation addresses itself to the above critical interface considerations, and it has not been the intent of this report to show every calculation.

Figure 47 shows the temperature profile that was assumed for the D-shaped thrust reverser/nozzle assembly in the reverse mode. The data were provided by Air Design Engineering, and it is based on extrapolated YC-14 (CF6 vs. F101 core temperatures were ratioed) reverse mode temperature measurements.

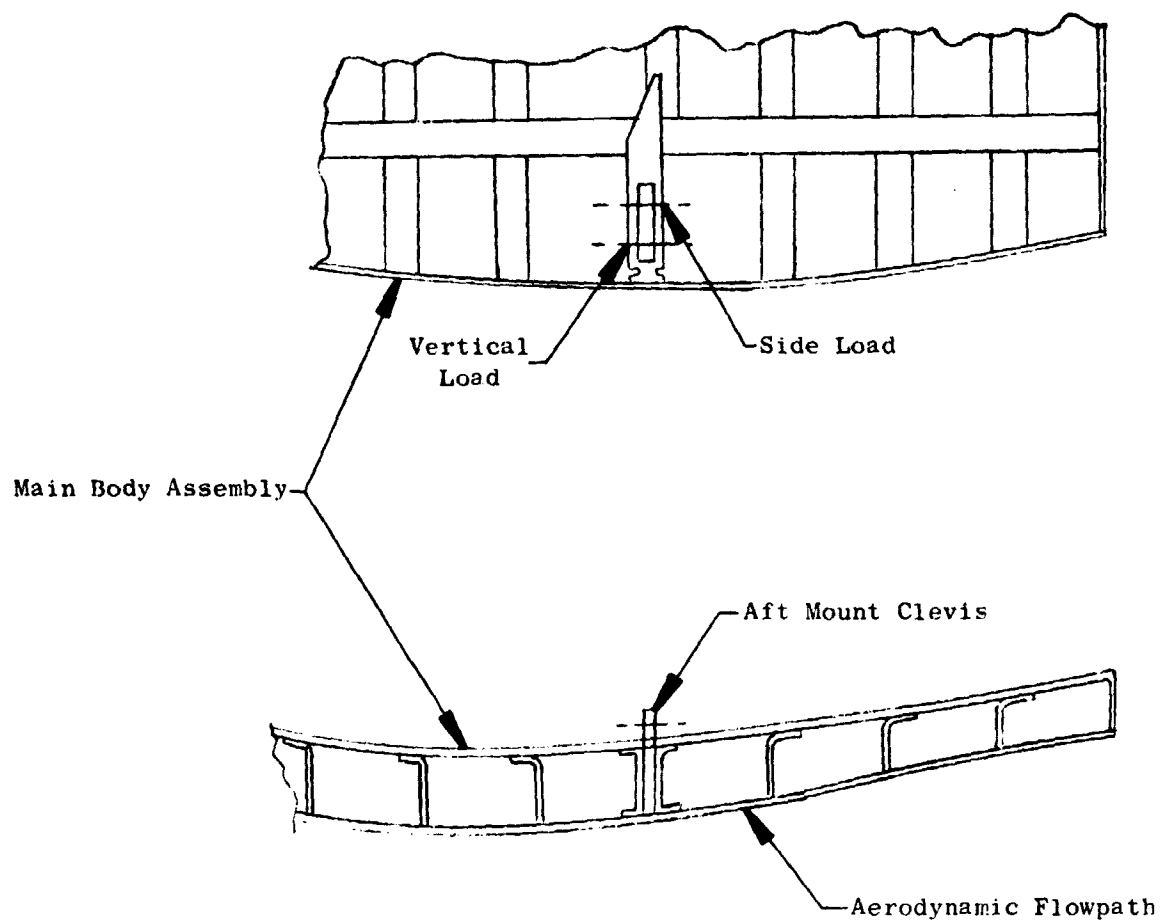


Figure 46. Aft Mount.

Sketch Location	Temperature	
	° F	K
1	400	477
2	400	477
3	462	512
4	735	664
5	940	778
6	1010	817
7	377	465
8	557	565
9	840	722
10	883	746
11	352	451
12	357	454
13	743	668
14	698	643

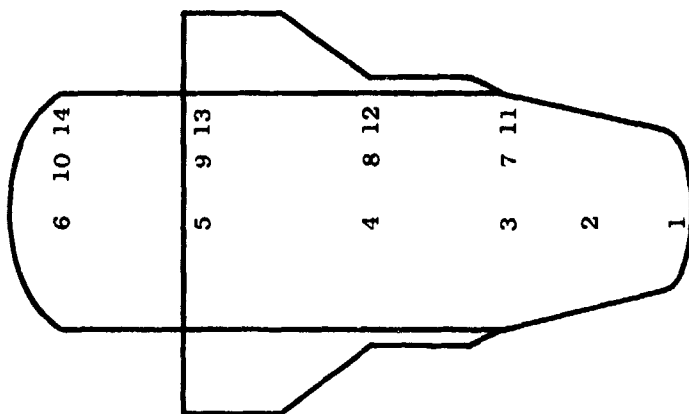
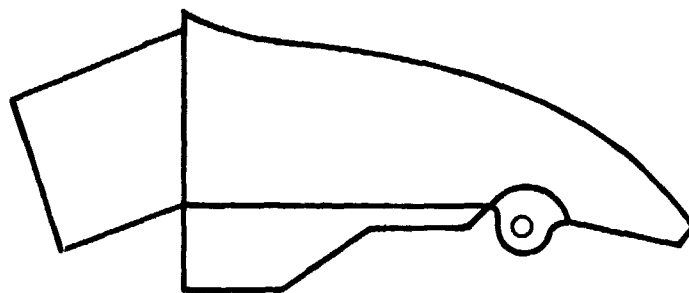


Figure 47. Estimated Temperature Distribution.

## APPENDIX

### QCSEE/OTW DRAWING LIST

56J119627-501 (Info Only)	Splitter Assy - Fan Cowl
57E119900	Ring, Splitter
56E119901	Skins, Splitter
56E119902	Splitter Assy, Fan Cowl
56J119903	Specification Control Drawing OTW Noz/QCSEE Tooling
56E119904	Clamp Block Assy, Splitter Assy Sta. 239.600
56E119905	Skins, Splitter
56E119906	Ring, Splitter
56J119907	Nozzle Assembly, Exhaust, Aft
56J119908	Body Assy, Nozzle, Aft Exhaust
56J119909	Skin, Body Upper, Aft Nozzle Spec Control
56E119910	Skin, Body Lower, Aft Nozzle Spec Control
56E119911	Housing Assy, Thrust Rev. Pivot Hub, Aft Nozzle
56C119912	Hub, Thrust Rev. Pivot, Aft Nozzle
56C119913	Pin, Thrust Rev. Pivot, Aft Nozzle
56D119914	Jackscrew Flap Positioning, Aft Nozzle
56D119915	Trunnion Flap, Jackscrew, Aft Nozzle
56D119916	Bracket, Jackscrew, Trunnion Aft Nozzle
56J119917	Bracket, Side-Mounting Aft Nozzle
56J119918	Door Assembly, Blocker Thrust Reverser
56E119919	Skin, Blocker Door, Thrust Reverser Spec Cont.
56D119920	Hinge Relief Flap Center
56J119921	Strut Assy, Fwd Positioning, Thrust Reverser
56J119922	Spacer Assy.-60° Positioning, Thrust Reverser
56J119923	Spacer Assy 70° Positioning, Thrust Reverser
56J119924	Lip Assy, Forward, OTW/QCSEE Thrust Reverser
56J119925	Flap Assy, Side, Thrust Reverser
56E119926	Skin, Side Flap, Aft Nozzle Spec Control
56D119927	Socket, Jackscrew, Aft Nozzle
56J119928	Plate Assembly, Side, Thrust Reverser
56E119929	Clevis, Lower Mount Aft Nozzle
56D119930	Specification Control Drawing Blocker Door Flap
56C119931	Specification Control Drawing, Plate
56C119932	Specification Control Drawing Blocker Door Flange
56C119933	Specification Control Drawing Trunnion Bearing
56C119934	Specification Control Drawing, Bar
56C119935	Specification Control Drawing Frame
56C119936	Specification Control Drawing Flange
56J119941	Extension Assy and Installation Fan Cowl
56E119942	Rings and Skin, Fan Cowl Extension Assy Spec Control Dwg
56J119943	Hard Wall Panel Assy, Fan Cowl Extension

56J119944	Acoustic Panel Assy, Fan Cowl Extension
56J119945	Skins, for Treated Panels Fan Cowl Extension Spec Control Drawing
56J119946	Adapter Assy
56J119947	Rings and Skins, Adapter Assy Spec Control Dwg
56J119948	Boattail Assy, Pylon
56J119949	Hinge Fitting, Fan Cowl Extension Assy